Summary of the Beaufort Sea Shelf Ecosystem Research Initiative

Hoover, C., Chmelnitsky, E., Cobb, D., Michel, C., Niemi, A., Ramlal, P., Walkusz, W., Swanson, H. Reist, J., Nielsen, O., Postma, L., Higdon, J., Ferguson, S., Young, R., and Loseto, L.

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Fisheries and Oceans Canada
501 University Crescent
Winnipeg, MB R3T 2N6

2013

Canadian Technical Report of Fisheries and Aquatic Sciences 3078

Canadian Technical Report of Fisheries and Aquatic Sciences

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by

Hoover, C., Chmelnitsky, E., Cobb, D., Michel, C., Niemi, A., Ramlal, P., Walkusz, W., Swanson, H. Reist, J., Nielsen, O., Postma, L., Higdon, J., Ferguson, S., Young, R., and Loseto, L.

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Cat. No. FS 97-6/3078E ISSN 0706-6457 (print version)
Cat. No. Fs 97-6/3078E ISSN 1488-5379 (electronic version)

Correct citation for this publication:

Hoover, C., Chmelnitsky, E., Michel, C., Niemi, A., Ramlal, P., Walkusz, W., Swanson, H. Reist, J., Nielsen, O., Postma, L., Higdon, J., Ferguson, S., Young, R., and Loseto, L. 2013. Summary of the Beaufort Sea Shelf Ecosystem Research Initiative. Can. Tech. Rep. Fish. Aquat. Sci. 3078: ix + 87 p.

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ABSTRACT

Hoover, C., Chmelnitsky, E., Michel, C., Niemi, A., Ramlal, P., Walkusz, W., Swanson, H. Reist, J., Nielsen, O., Postma, L., Higdon, J., Ferguson, S., Young, R., and Loseto, L. 2013. Summary of the Beaufort Sea Shelf Ecosystem Research Initiative. Can. Tech. Rep. Fish. Aquat. Sci. 3078: ix + 87 p.

This document provides an overview of the Beaufort Sea Shelf Ecosystem Research Initiative for the Arctic Aquatic Research Division of the Central and Arctic region of Fisheries and Oceans Canada, and the research completed in association with this initiative. Multiple research projects are highlighted under this initiative as they contribute to the understanding of the Beaufort Sea Shelf ecosystem. Ecosystem research within the area is highlighted through the development of this initiative along with past and future research efforts. Finally, results from ten projects are presented along with a synthesis of potential indicators and stressors to the ecosystem.

Keywords: Ecosystem Research Initiative, Beaufort Sea Shelf, Ecosystem Based Management, Arctic Food Web, Stressors, Ecosystem modeling

RÉSUMÉ

Hoover, C., Chmelnitsky, E., Michel, C., Niemi, A., Ramlal, P., Walkusz, W., Swanson, H. Reist, J., Nielsen, O., Postma, L., Higdon, J., Ferguson, S., Young, R. and Loseto, L. 2013. Summary of the Beaufort Sea Shelf Ecosystem Research Initiative. Can. Tech. Rep. Fish. Aquat. Sci. 3078: ix + 87 p.

Le présent document présente un aperçu de l'initiative de recherche écosystémique sur le plateau de la mer de Beaufort de la Division de la recherche aquatique de l'Arctique de la région du Centre et de l'Arctique de Pêches et Océans Canada, ainsi que de la recherche effectuée en lien avec cette initiative. L'initiative met en valeur de nombreux projets de recherche puisqu'ils contribuent à la compréhension de l'écosystème du plateau de la mer de Beaufort. La recherche écosystémique dans cette région est également mise en évidence par l'initiative, de même que les efforts de recherche passés et futurs. Enfin, les résultats de dix projets sont présentés en même temps qu'un résumé des indicateurs et des facteurs de stress possibles de l'écosystème.

Mots clés : l'initiative de recherche écosystémique; le plateau de la mer de Beaufort; la gestion écosystémique; le réseau alimentaire de l'Arctique; les facteurs de stress; modélisation de l'écosystème.

INTRODUCTION

ECOSYSTEM RESEACH INITIATIVE (ERI)

In 2008, the Department of Fisheries and Oceans Canada (DFO) outlined a five-year research plan (2007-2012) that identified the importance of an ecosystem-based management (EBM). This integrated plan also provided DFO Science with direction to develop new knowledge and methods for providing advice to support policy and decision making (DFO 2008). In order to facilitate EBM, DFO launched the Ecosystem Research Initiatives (ERIs) in priority areas within Canada that represented seven unique aquatic ecosystems. The ERI program aimed to increase DFO's understanding of aquatic ecosystem health and the potential impacts of environmental and climate change on these ecosystems, as well as develop tools in support of a Departmental EBM.

The seven ERIs were established within each DFO Region in both marine and freshwater environments (Figure 1). These ERIs served as a pilot for DFO's EBM focusing on regional research priorities including fish population and community productivity, habitat and population linkages, climate variability, ecosystem assessment, and management strategies (DFO 2008). The general themes within each ERI included: 1) understanding ecosystem processes, 2) understanding the impacts of climate variability, and 3) developing tools for an EBM (DFO 2008). The resulting research findings and new knowledge acquired from these ERIs aimed to be beneficial to decision makers and the international community and as such results were meant to be communicated widely (e.g., publication, conference presentations, etc.).

A key aspect of the ERIs was the assessment of ecosystem stressors and the development of approaches to determine the cumulative impacts of stressors on diverse ecosystems. This involved integrating the results from multiple studies to develop a comprehensive picture of key ecosystem linkages and drivers that could be monitored to evaluate impacts. Having the ERIs take an integrated approach with multiple projects

under one umbrella, created the opportunity for individual researchers to link various aspects of the ecosystem together.

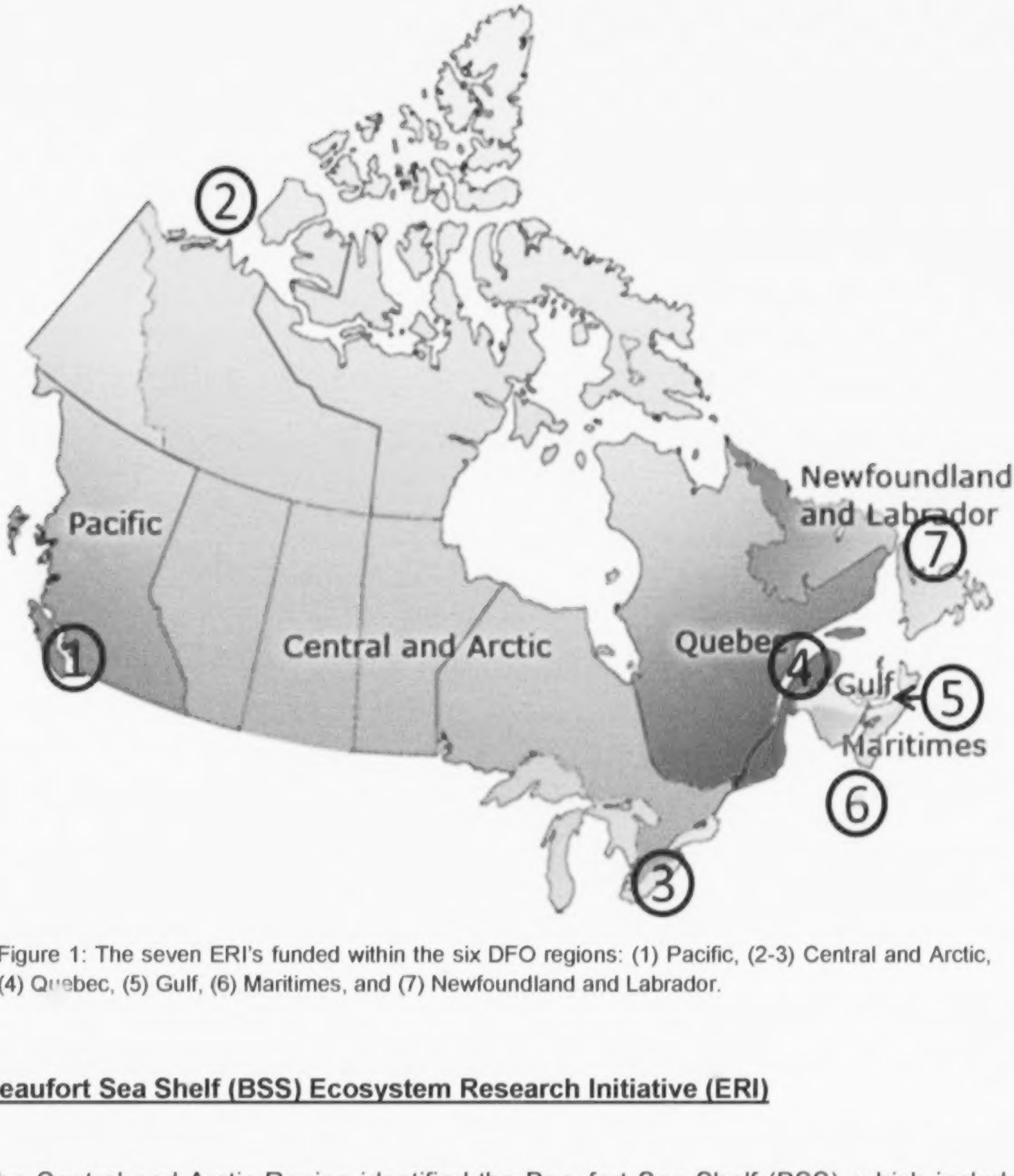


Figure 1: The seven ERI's funded within the six DFO regions: (1) Pacific, (2-3) Central and Arctic, (4) Quebec, (5) Gulf, (6) Maritimes, and (7) Newfoundland and Labrador.

<u>Beaufort Sea Shelf (BSS) Ecosystem Research Initiative (ERI)</u>

The Central and Arctic Region identified the Beaufort Sea Shelf (BSS), which includes the Tarium Niryutait Marine Protected Area (TN MPA) (Figure 2), as a priority research

area in the Arctic for the ERI program. The BSS is a complex, ecologically critical area representing many Arctic species and important trophic interactions (Cobb *et al.* 2008). In order to identify a number of these important areas and interactions, DFO has identified, based on criteria, 18 Ecologically and Biologically Significant Areas (EBSAs) within the Beaufort Sea and Amundsen Gulf (Figure 3; Paulic *et al.* 2009).

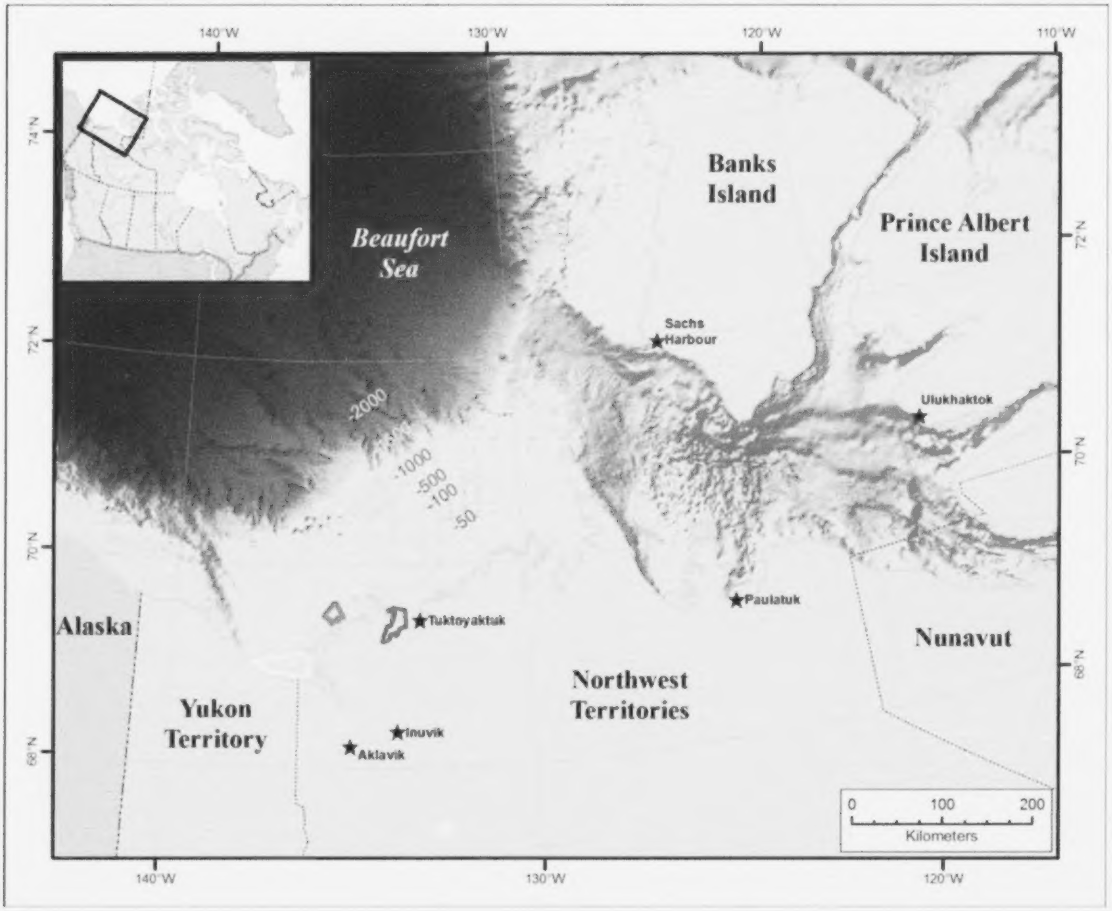


Figure 2: Map of the coastal areas of the BSS with depth contour lines ranging from light blue (20m) to darker blue (2000m). Local communities are identified on the map. The Tarium Niryutait Marine Protected Area (TN MPA), identified by the three colored areas, is protected for being one of the largest summer aggregations of belugas in the world. The MPA includes 3 areas: Niaqunnaq/ Shallow Bay (yellow), Okeevik/ East Mackenzie Bay (red) and Kittigaryuit/ Kugmallit Bay (blue).

Each EBSA is considered to have particularly high ecological or biological significance, suggesting a more conservative management approach may be warranted to protect

the structure and/or function within each of the areas (DFO 2004). In addition, to the ecological significance the BSS is a culturally significant area for Inuvialuit and Gwich'in people for subsistence harvest of fish and marine mammals (Cobb *et al.* 2008). The BSS ecosystem faces a number of current and future stressors, particularly oil and gas exploration, in addition to climate change driven impacts. Recently observed changes in sea ice coverage and duration is likely impacting species and their supporting ecosystem within the BSS (Stroeve *et al.* 2011). Potential changes to the food web include changes in species abundance and distribution, introduction of disease, and shifts in prey quality and quantity. In order to effectively manage current activities, prepare for the changes in the BSS, and anticipate future development of the region, an ecosystem-based approach was an ideal framework to ensure long-term ecosystem health and food security in the area (Wieckowski *et al.* 2010). The BSS ERI research program has the ability and flexibility to respond to various priority challenges by addressing a wide range of ecologically significant species and ecosystem linkages (Niemi *et al.* 2012).

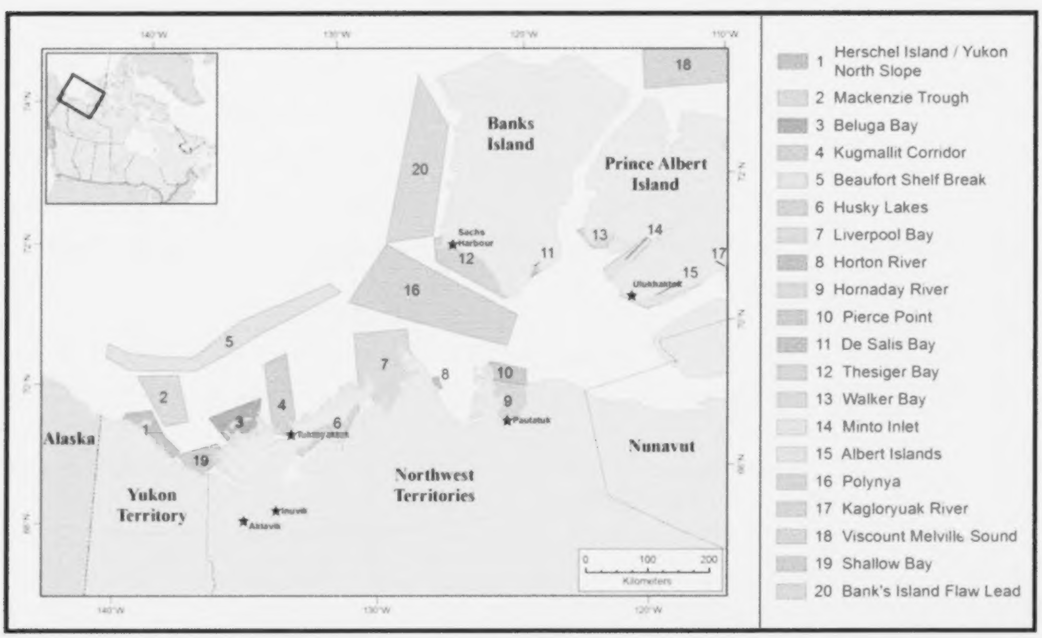


Figure 3: Ecologically and Biologically Significant Areas (EBSAs) in the Beaufort Sea, Amundsen Gulf and Viscount Melville Sound (Paulic *et al.* 2009).

Program Goals and Objectives

The overall goal of the BSS ERI program was to support DFO's ability to address the cumulative impacts of multiple stressors in the BSS. To do this the objectives of the BSS ERI were to: 1) assess ecosystem linkages and processes in support of ocean health and productivity; 2) integrate research in support of modelling that addressed ecosystem questions from managers (e.g., DFO's Oceans Program, Habitat, and Fisheries and Aquaculture Management (FAM)); and, 3) build and maintain partnerships while meeting co-management obligations to ensure future sustainability and health of the BSS. The ERI was meant to underpin informed decision making by regulatory authorities and co-management committees with the ultimate goal of supporting sustainable development in the Beaufort Sea.

In order to achieve these objectives a baseline understanding of the ecosystem structure, function and health was needed, along with the need to characterise the variability of ecosystem parameters to define the range of ecosystem response to stressors. Thus, the BSS ERI focused on eight ecosystem components: 1) fish as pivotal ecosystem components; 2) seasonal and migration patterns of bowhead whales (*Balaena mysticetus*); 3) health of beluga whales (*Delphinapterus leucas*); 4) beluga distribution in relation to ice; 5) beluga stock delineation; 6) disease in marine mammals; 7) lower trophic dynamics of the Beaufort Sea; and 8) primary productivity in the Beaufort Sea, including implications of a changing climate (DFO 2008). Some of the key outputs of the program included the collection of data to be tested and used for long term monitoring for both the TN MPA and Integrated Oceans Management Plan (IOMP). These monitoring efforts would also provide the baseline needed to begin assessing cumulative impacts.

Integrating the ERI through ecosystem modelling

Ecosystem Modelling was considered an important component of the DFO ERIs. Following an EcoNet workshop on Ecosystem Modelling in Halifax in 2009, researchers working within different ERIs, including the BSS ERI, decided this was an important tool to help integrate knowledge across various projects within the same ecosystem. In

order to explore the potential of adding this component to the ERI a workshop was held at the Freshwater Institute in Winnipeg (2009) that included Science and clients (Oceans Program, Habitat, co-management boards). The group discussed how to move forward with EBM in the BSS and the output of the meeting was twofold: first gaps were identified, including gaps in our understanding of ecosystem linkages (Figure 4); and second it was decided an ecosystem model would be used to bring together other components of ERI research into one dynamic model (Figure 5). All clients agreed that the use of an ecosystem model to manipulate stressors and integrate cumulative impacts would be an ideal approach to integrate multiple studies across trophic levels, and to develop a better understanding of ecosystem structure and function. Additionally, a general emphasis was put on existing and future data management and synthesis of data to feed into the model. The workshop resulted in recommendations for how to proceed, and a formal proposal process was put in place that required proponents to outline how their research fed into the gaps and needs required for the ecosystem model (Wieckowski *et al.* 2010).

The Ecopath with Ecosim approach was chosen following a series of model development meetings as the approach for the BSS ERI due to its widespread use in academia and other DFO regions (Wieckowski *et al.* 2010; DFO 2013). The modelling efforts to date have also been very well received by the co-management partners (Fisheries Joint Management Committee (FJMC)), and co-management buy-in is a critical requirement for any Arctic initiative. The work from the BSS ERI has also contributed significantly to the development of the TN MPA monitoring program, Many of DFO's recommendations for monitoring and follow-up were included in the conditions for approval. This work will help the Government of Canada better respond and prepare for future development and monitoring strategies.

Research Approach

The approach to funding research projects included targeting studies at different trophic levels to integrate them in addressing research areas such as; (1) covering all trophic

levels in the ecosystem, (2) integrating research among trophic levels to better understand ecosystem processes, and (3) identifying and gathering information on stressors at the ecosystem and species level. Integration of ERI research occurred by using common approaches to identify dietary markers such as stable isotope and fatty acid to identify trophic linkages, and synthesizing research projects together into two food web based models. A summary of ERI projects and the contribution of funding from the ERI is presented in Table 1. Here, each research project has identified how much of their total project funding was contributed from the ERI program along with the trophic level or species of focus for each project. Prior to the ERI program, data were collected under the Northern Coastal Marine Studies Program from 2003 to 2009 which utilised surveys on the CCGS *Nahidik* (see Walkusz and Williams 2013 for a summary of projects). Many projects under the ERI continued sampling after the *Nahidik* surveys concluded, or leveraged funding to analyse data collected under this program. Funding for each project was leveraged with the exception of the ecosystem modelling component.

The purpose of the remainder of the document is to provide a brief overview for each of the ten individual ERI projects. For each project, a brief introduction is provided along with highlighted results and any gaps identified as a result of the research conducted. Projects are presented by ascending trophic level starting with the bottom of the food web and ending with the ecosystem model. After each project is introduced, a summary of ecosystem stressors is presented with respect to individual species or trophic levels studied. Finally, a summary of lessons learned from the ERI experience and recommendations for future research activities in the Beaufort Sea are presented. A diverse array of reports and journal articles resulted from the BSS ERI research. A full list of research articles is provided in Appendix A.

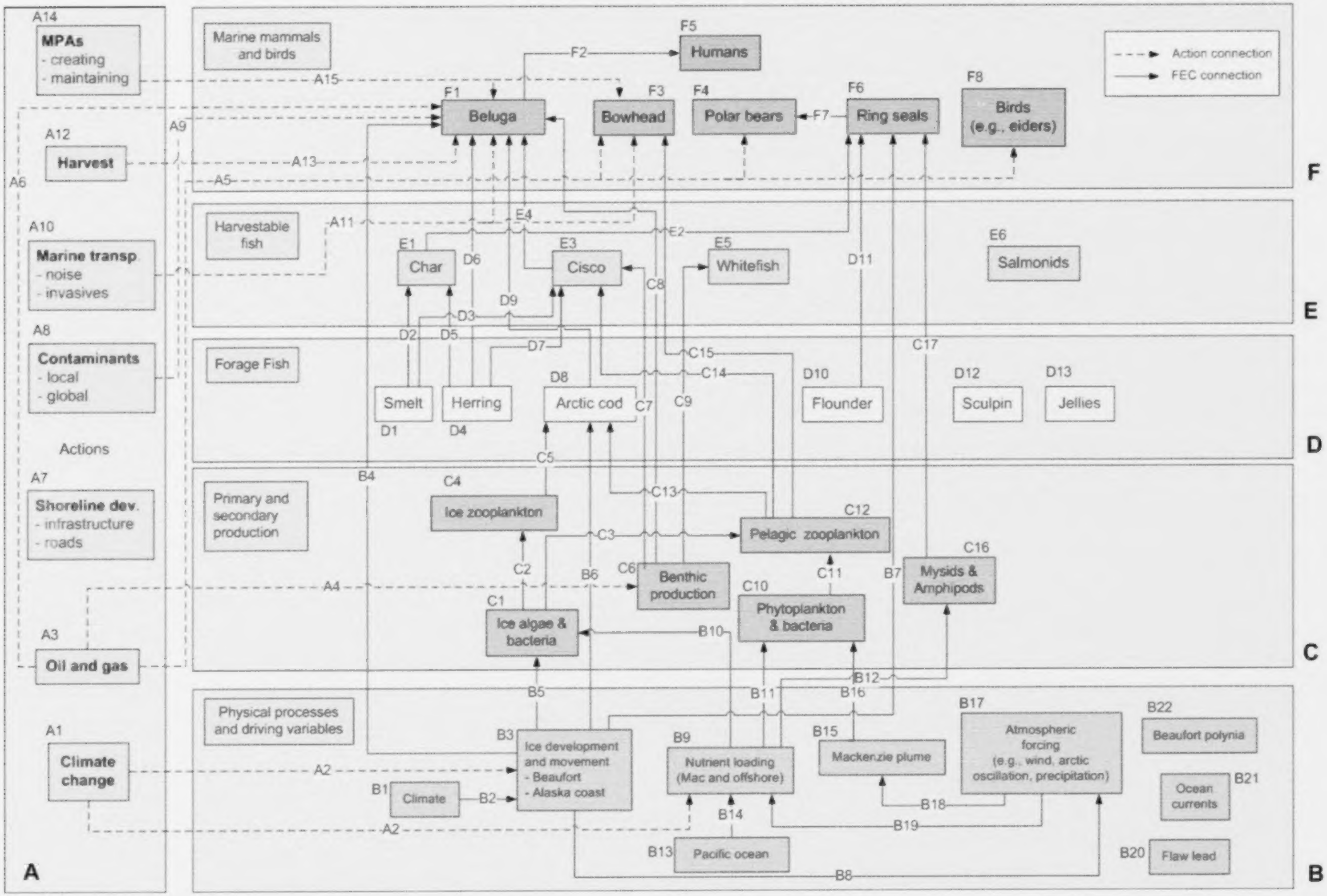


Figure 4: Summary of Beaufort Sea knowledge created during 2009 meetings at DFO with ESSA and other consultants. This figure represents different ecosystem components and stressors with links indicated by arrows. For a full description of all components and stressors please see Wieckowski *et al.* (2010).

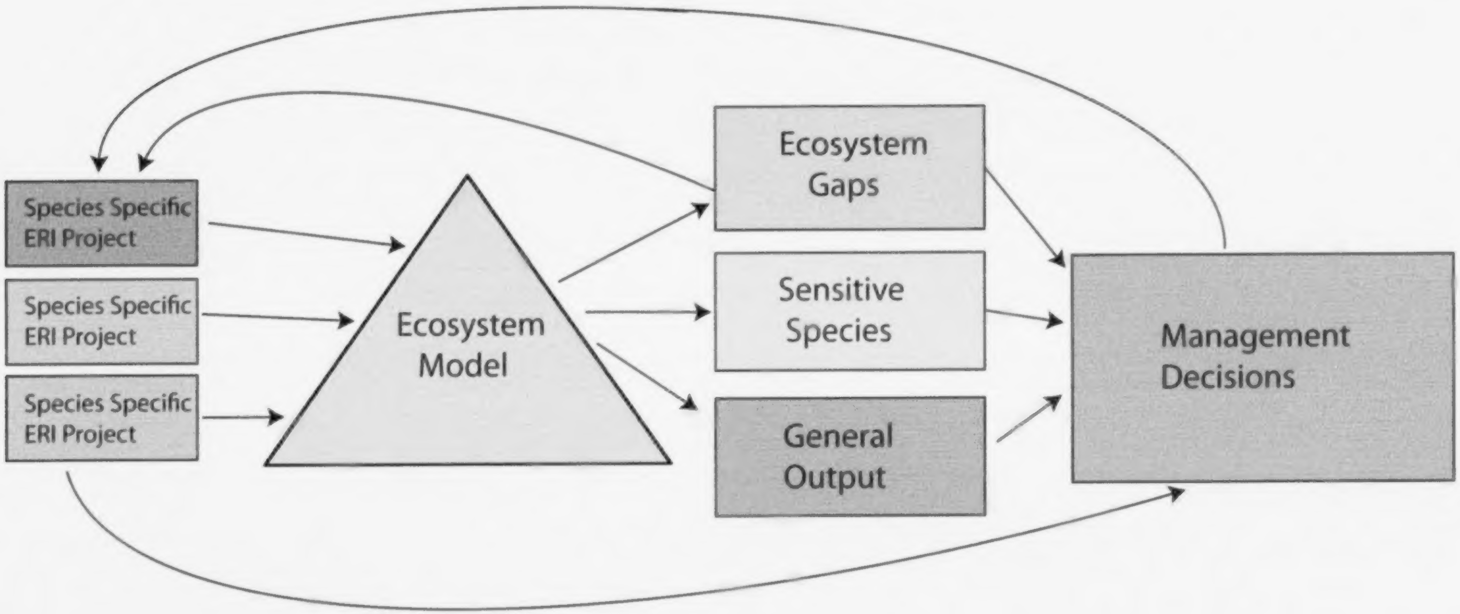


Figure 5: Flow chart identifying the relationship between species based research projects, the ecosystem model and how they feed into management decisions.

Table 1: Contribution of ERI funds to individual projects.

Project	% of project/ program funding from ERI	Trophic Level of Research Project	Author for each project summary
Physical, chemical, and biological conditions that define ecosystem architecture	5%	Primary Producers, Environmental Variables	Christine Michel, Andrea Niemi
Structure of lower trophic levels in the nearshore regions of the Beaufort Sea	10%	Benthos, Environmental Variables	Patricia Ramlal
Arctic Coastal Ecosystem Studies (ACES) program	10%	Fish, Benthos	Wojciech Walkusz, Lisa Loseto
Understanding fish diets through stable isotope analysis at Philips Bay	20%	Fish	Heidi Swanson, Jim Reist
Identification of emerging infectious disease threats to the marine mammals of the Beaufort Sea	10%	Marine Mammals	Ole Nielsen
Distribution, movements and behaviour of marine mammals in the Beaufort Sea and Amundsen Gulf	<5%	Marine Mammals	Lois Harwood
Beluga Health Program	25%	Marine Mammals	Lisa Loseto
Genetic monitoring and conservation of beluga whales in the western Canadian arctic	18%	Marine Mammals	Lianne Postma
Observations of killer whales in the Beaufort Sea	80%	Marine Mammals	Jeff Higdon, Steve Ferguson
Ecosystem modelling of the Beaufort Sea	100%	Whole Ecosystem- All Trophic Levels	Carie Hoover

SECTION 1: PHYSICAL, CHEMICAL, AND BIOLOGICAL CONDITIONS THAT DEFINE ECOSYSTEM ARCHITECTURE

BACKGROUND

The Beaufort Sea is influenced by various oceanographic forcings. These include large-scale circulation in the offshore Beaufort gyre, nutrient-rich waters from the Alaskan Coastal Current to the west, the influence of freshwater dissolved to the east, and particulate material input from the Mackenzie River. The Beaufort Sea is also strongly impacted by changes in sea ice along with increasing frequency and severity in storms associated with climate warming. In addition, this area is targeted for hydrocarbon exploration and exploitation. Recent studies investigating factors that control the productivity of the Beaufort Sea highlight the importance of nutrient-rich water upwelling (Williams and Carmack 2008), which can trigger large increases in productivity (Mundy *et al.* 2009, Tremblay *et al.* 2011). The dynamics of the nearshore marine ecosystem of the Beaufort Sea and the TN MPA, where an abundance of marine mammals congregate in summer, is still poorly understood.

This research was formulated to address priority indicators highlighted for the TN MPA, including stable isotopic signatures for lower trophic levels, and fundamental indicators of ecosystem structure such as currents, temperature, salinity, suspended sediments and chlorophyll *a*. In this study we targeted critical gaps and objectives identified for the Beaufort ERI; in particular, understanding the ecosystem structure and function and incorporating tools such as stable isotopes and fatty acids to characterize food web transfers. The aim of the project was to: (1) gain a better understanding of the factors that influenced the type and magnitude of primary production and therefore the elements of ecosystem architecture and food webs; (2) study how these factors change in response to various stressors in the system; and, (3) how these changes influence food web transfers (the channelling of energy and materials to pelagic and benthic communities) and ecosystem services. Since different types of primary producers will support different types of fish, benthic organisms, and marine mammals, it is essential

to understand changes in the structure, as well as overall productivity of the ecosystem. Our results are used in ecosystem modelling by our DFO ERI partners, with tracers such as fatty acids and stable isotopes serving to identify food web transfers.

The ERI supported research has allowed a better characterization and understanding of the dynamics of the nearshore Beaufort Sea ecosystem. In addition to pursuing the integration and interpretation of original results obtained during ArcticNet expeditions, research was conducted as part of the Arctic Coastal Ecosystem Studies (ACES) program, an ecosystem-based initiative established in 2010 (see Section 3 for additional results). The integration and analyses of baseline physical, chemical and biological data collected in the TN MPA allowed us to identify factors that influence overall productivity and food web transfers within the BSS ecosystem. In addition, the data collected during the ERI are being used to feed into ecosystem modelling to provide parameter estimates and help predict potential changes in ecosystem pathways from primary producers to higher trophic levels (Section 10).

RESULTS FROM ERI RESEARCH

Integrated results from data collected at 14 nearshore stations (Figure 6), together with monitoring of ocean variables, have identified the following:

- A high spatial heterogeneity in physical, chemical and biological conditions in the nearshore study area related to the strong influence of the Mackenzie River, and a marine influence to the east (Figure 7). Since the different water column characteristics determine the structure and flow of materials in the food web, these results confirm different food web patterns in the areas influenced by the Mackenzie River (e.g. stations 4 and 5, figure 6) and other areas under marine influences (e.g. stations 6 and 11, figure 6) (also see Juul-Pedersen *et al.* 2008). The difference in influences also highlight that the different areas of the nearshore Beaufort Sea and the TN MPA are structured and respond to different environmental forcing.

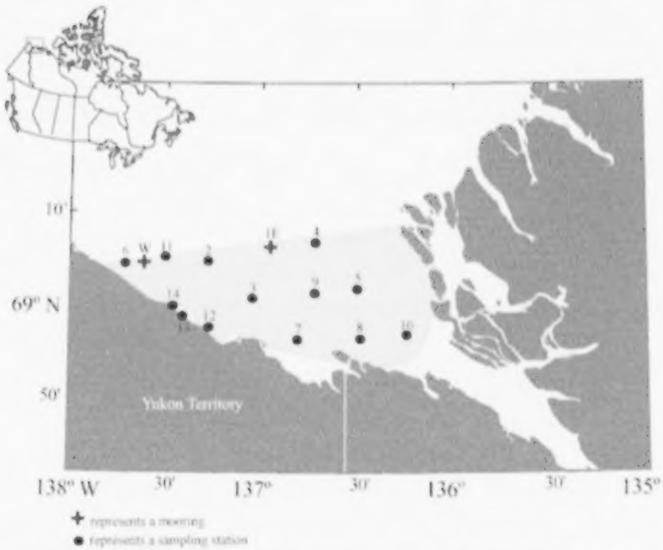


Figure 6. Sampling locations for biological, chemical and physical water column variables in the Niaqunnaq sub-area of the TN MPA during the Arctic Coastal Ecosystem Studies Program in 2010.

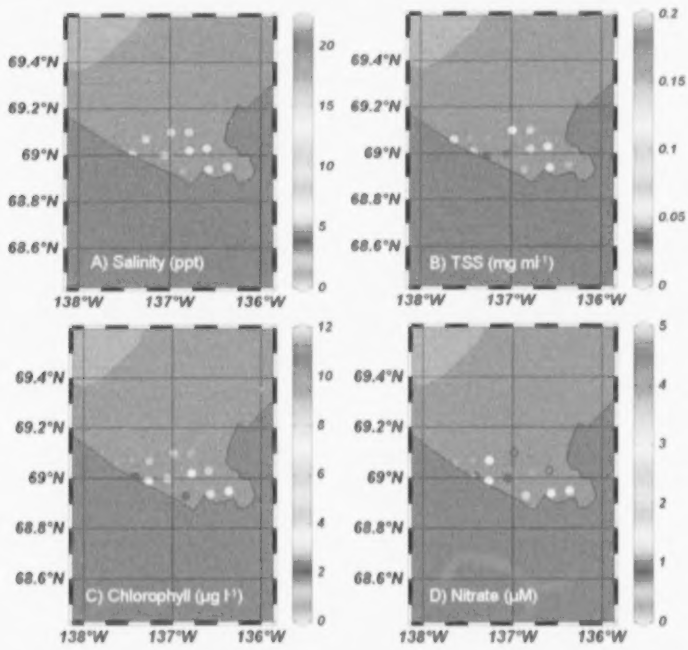


Figure 7. Spatial distribution of salinity (A), total suspended solids (B), chlorophyll a (C) and nitrate (D) in the nearshore Beaufort Sea, showing the marine and freshwater (Mackenzie River) influences on the western and eastern side of Shallow Bay, respectively.

- Two oceanographic moorings (1E and W in Figure 6) captured a storm and its impact on the ecosystem during our study. The eastern mooring (1E) recorded the strongest response to the storm as shown in figure 8. These results show the importance of storms in structuring the nearshore ecosystem of the Beaufort Sea, and their potentially lasting effect.

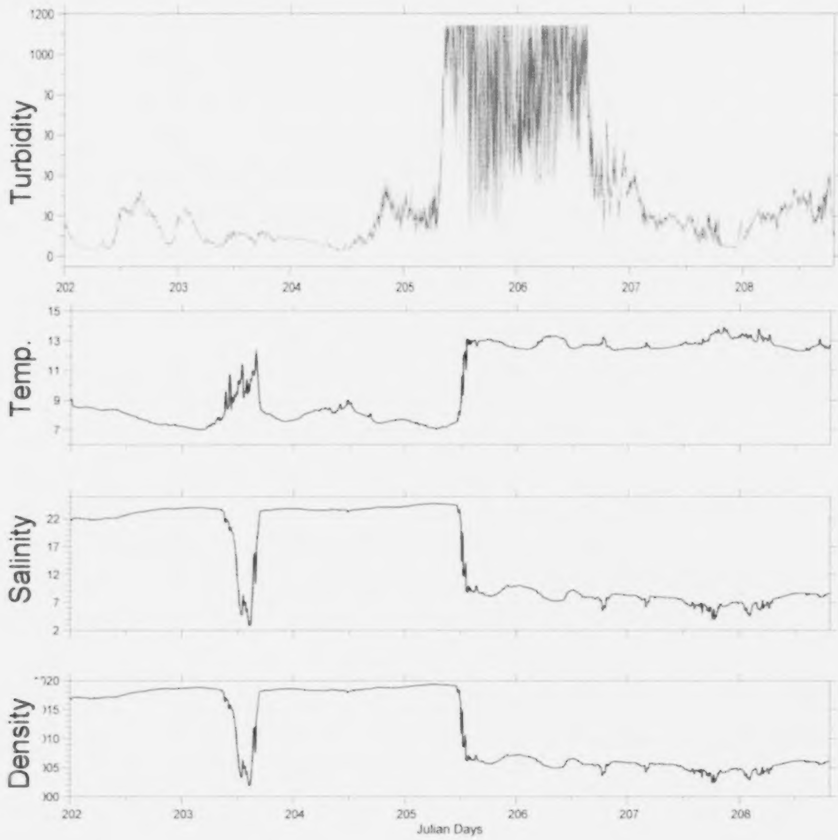


Figure 8. Temporal changes in turbidity, temperature, salinity and density at the eastem mooring station (Fig. 6 mooring 1E), showing the sustained impacts of a storm on those water column properties (days 205-208).

- An important climate-associated change in the Beaufort Sea is the increasing occurrence and intensity of storms (Manson and Solomon 2007) Our results show the pronounced effect of storms on biological processes in the nearshore Beaufort Sea, calling for urgent efforts to better understand and predict the biological impacts of increasing storm events on coastal Arctic ecosystems.

- During the period of this study, the biomass of primary producers in the nearshore study area was low. This was largely attributed to the high suspended load from the Mackenzie River, indicating that the nearshore food web does not depend on pelagic primary production originating in this area. It is therefore very unlikely that in situ production in the nearshore would support energy requirements of the local food web marine mammals visiting the area. This work also provided an opportunity to develop a new remote sensing algorithm to reliably estimate and map the distribution of suspended sediments in the nearshore Beaufort Sea (see Figure 9; Tang *et al.* 2013), with leveraged funds from the Canadian Space Agency.

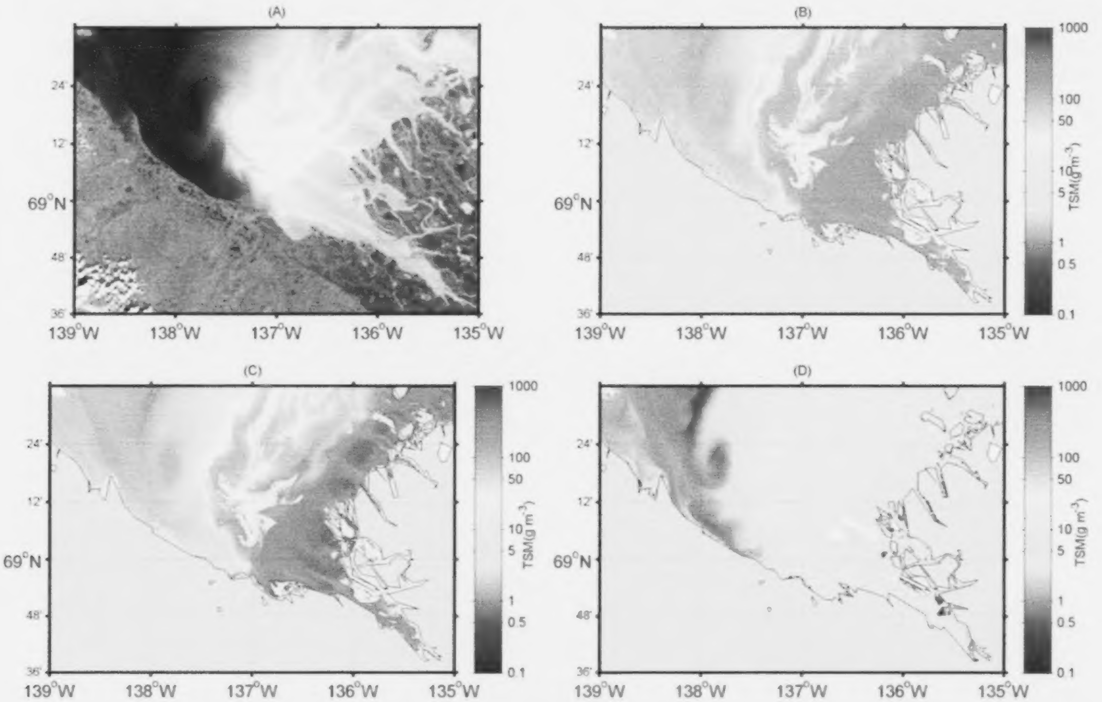


Figure 9. Full resolution MERIS image of the Mackenzie River estuary, eastem Beaufort Sea, acquired on 21 July 2010. (A) Shows the true color image of suspended sediments, while B-D display different algorithms predicting sediment flows out of the Mackenzie River: (B) using the Support Vector Machine (SVM) algorithm, (C) using a piece-wise algorithm, and (D) using an CR2 algorithm. The SVM and piecewise algorithms have been developed by DFO with support from ERI

GAPS IDENTIFIED

The following science and knowledge gaps have been identified in the context of multiple stressors including climate-associated trends and changes. These gaps have been identified as needing to be addressed not only for ecosystem monitoring and conservation purposes, but also for the sustainable management of activities in the Beaufort Sea.

First, there is still a lack of knowledge on rates of productivity and rates of transfer of biomass and materials to pelagic and benthic grazers in the nearshore Beaufort. These measurements are essential, as static measures of biomass do not reflect how much material is available to the food web to support higher trophic levels.

Second, there is an urgent need to better constrain primary production estimates in the nearshore Beaufort and extending offshore. Recent studies showed that changes in ice conditions in the Beaufort would have increased primary production between two and four fold in past years (Tremblay *et al.* 2011), as there are highly productive phytoplankton blooms under the ice (Arrigo *et al.* 2012). These orders of magnitude changes in production are not accounted for in models of the Beaufort Sea, nor in global models.

Third, because the flow of energy and material in marine food webs and in the Beaufort Sea is strongly influenced by the amount and type of primary producers and by the amount of material that is recycled by bacteria and other decomposers, it is essential to improve our estimates of the flow of materials within different ecosystem compartments, i.e. how much is recycled by bacteria (and does not flow to other trophic levels) versus how much is transferred to grazers and upper trophic levels.

Last, essential research on the impacts and compounding effects of climate-associated changes, such as increased storm occurrence and decrease in sea ice, on ecosystem architecture (physical, chemical and biological processes) is required to foster

scientifically-defensible adaptive strategies and sustainable economic opportunities in Arctic coastal communities.

SECTION 2: STRUCTURE OF LOWER TROPHIC LEVELS IN THE NEARSHORE REGIONS OF THE BEAUFORT SEA

BACKGROUND

The BSS provides habitat for higher trophic level species such as fish and marine mammal populations; however, little is known about this habitat, including abundance of lower trophic level organisms and the environmental variables important to them. The need to understand the basic ecology and food web structure of the BSS is imperative as changes in the environment occur from various factors including: climate change, increased oil and gas exploration and increased marine traffic. For example, changes in the degree of permafrost, increased run-off and greater use of the river may lead to an increased sediment load from the river to the Beaufort. This will have immediate effects on primary production as changes in light and nutrient regimes can affect benthic organisms as their habitat is altered. These changes will ultimately lead to changes in the higher levels of the food web. The purpose of this project was to provide the baseline data to develop a model of the food web of the lower trophic levels of the nearshore area of the Beaufort Sea. Raw data was acquired during the CCGS *Nahidik* surveys (as part of the Northern Coastal Studies Marine Program) with the ERI component of the project focusing on the analysis of these data.

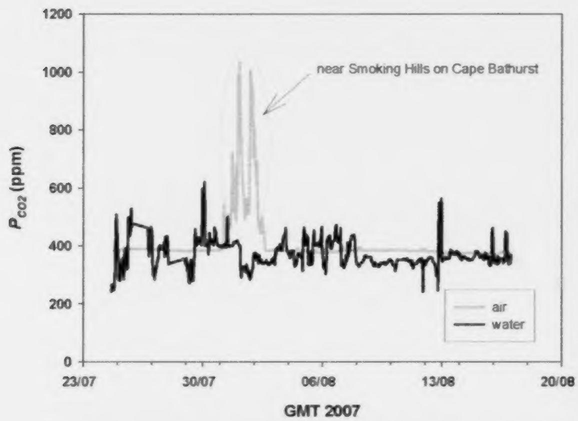
Measurements of surface water carbon dioxide (CO_2), and oxygen (O_2) concentrations, which provide an estimate of the mixed layer primary production, were taken to provide baseline values of environmental conditions. In addition, water, sediment and biotic samples were collected for chemical analyses, biomass estimates, species identification, stable isotope measurements and fatty acid (FA) measurements. These lower trophic level organisms with faster turnover times are likely the first organisms to show the effects of alteration or degradation in the ecosystem. Research focused on higher trophic level species often fails to capture this important relationship between the environment and the base of the food web. This research identifies the links between the environment, producers, and lower trophic level organisms to establish the

components of the lower trophic levels that support fish and mammals in the coastal Beaufort Sea. This understanding of the base of the food web is fundamental to assess potential changes in higher-level organisms. To understand the Beaufort Sea ecosystem, it is necessary to determine baseline environmental quality conditions, thus increasing knowledge of productivity. For the purpose of this exercise, production is defined as: (a) primary (bacterial and algal) in the water column, ice edge and ice/water interface (b) secondary (zooplankton) in the water column, or (c) benthic production (bacteria, microfauna, meiofauna, macrofauna, megafauna)

RESULTS FROM ERI RESEARCH

- Data collected from 2005-2008 annually included: water chemistry, algal samples, meiofauna samples, and carbon dioxide and oxygen gas fluxes. In addition, stable isotopes were taken from particulate organic matter, net plankton, some ichthyoplankton, zooplankton and sediments. Data has been compiled into a DFO database that will be used to develop lower food web models and to supply baseline information to other research projects.

- Figure 10 shows the hourly P_{CO2} (carbon dioxide partial pressure) measurements from the *Nahidik* cruise of July and August of 2007. Of particular interest is the large atmospheric P_{CO2} encountered around the Smoking Hills of Cape Bathurst, coupled with the lower P_{CO2} in the surface water at the same time. Atmospheric P_{CO2} during the rest of the cruise (excluding the Smoking Hills) was 382 ± 5 ppm. This is remarkably close to the 2007 P_{CO2} value of 383.7 ppm as measured at Mauna Loa, Hawaii, where regular standardized measurements are recorded.



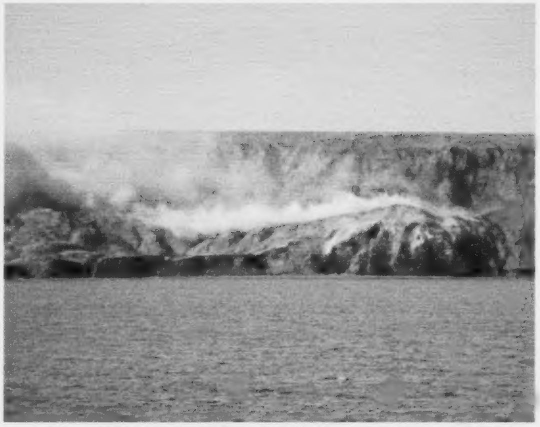


Figure 10. Partial pressure of CO2 in air and surface water in the Beaufort Sea as measured from hourly ship track from the *Nahidik* cruise (left). Smoking Hills of Cape Bathurst (right).

- Fatty acid (FA) analyses have been completed on biological materials and sediments. Preliminary analyses indicate there are differences in the FA composition of zooplankton from different size classes. In addition, the analysis reveals there is a FA stratigraphy (stratification) in the sediments. FA analyses are being tested to determine if this would be a useful tool in rapid assessment of changes to baseline conditions, as it can provide information on an organism's diet over time (especially higher trophic levels). This also allows spatial and temporal comparison of foraging patterns.

- A combined research team from DFO (Freshwater Institute, Institute of Ocean Sciences, and DFO Yellowknife office), the Polish Institute of Oceanology and the Canadian Museum of Nature collected data on water and sediment chemistry, and the distribution and biomass of phytoplankton, zooplankton and benthic invertebrates. Among the findings were that lipid dense, high calorie centric diatoms and protozoans are the main components of the phytoplankton biomass where bowheads feed (Section 6). High concentrations of this type of phytoplankton have not been detected elsewhere in the region.

GAPS IDENTIFIED

Physical processes such as upwelling events, river plume location and movement and weather, have a direct impact on the availability of nutrients that sustain production as well as the location that production will occur. These processes, while poorly understood, have the potential to alter production rates and impact multiple trophic levels throughout the food web. Future research should aim to bridge physical oceanography with biological data to allow the impacts of these processes to be quantified. In addition, bridging ERI data at different levels with other programs such as Canada's Three Oceans (C3O), the *Nahidik* or ArcticNet would bring together researchers to increase our knowledge of energy transfer in the system. With data from this program providing the baseline, future research should focus on continued data collection to assess any changes in the food web structure that may occur, and the physical stressors responsible for them.

SECTION 3: ARCTIC COASTAL ECOSYSTEMS STUDIES (ACES) PROGRAM

BACKGROUND

The Arctic Coastal Ecosystems Studies (ACES) program is a community based monitoring program that was developed to expand existing knowledge on fish ecology in the context of supporting research of ecosystem components in the Shallow Bay area of the TN MPA. ACES is also considered to be an evolution from the *Nahidik* fish program, which collected fish samples from boat based surveys in the shallow shelf area (~5-50m) to describe the food web. ACES is closely linked with the community of Aklavik, as they harvest fish and contribute to samples in Shallow Bay. In addition, fish collected under the ACES program are evaluated as potential beluga prey species in context with the beluga health monitoring program (Section 7). One of the means by which ACES and other TN MPA programs partner to enhance knowledge of ecosystem structure and function, is to maintain common sampling approaches. Here, a focus is placed on using stable isotopes (SI) and fatty acids (FA) at different trophic levels to gain baseline signatures for species and ecosystem components as well as to assess trophic linkages, and energy flow within the system. The 2010 ACES program sampled many components of the ecosystem and covered an expansive spatial area of Shallow Bay whereas, in 2011 the program focused on fish and invertebrate collections at Shingle Point for analysis of SI and FA (Figure 11). Changes in these parameters, detected through long-term monitoring efforts, will act as indicators of shifts in the ecosystem by incorporating the cumulative effects of multiple stressors. When a shift in the ecosystem is detected, a more comprehensive sampling program can be initiated to better understand the nature and causes of the change. During the ACES program, several scientific techniques were combined with community harvest methods in collaboration with expert fishermen in the Shingle Point area. To further develop our understanding of ecosystem structure and function, future development of this program into a long-term coastal monitoring program may include partnering with potential offshore fisheries research to take place under the Beaufort Regional Ecosystem Assessment (BREA)

funded program. Partnering with an offshore-based research program would spatially expand the sampling area under the *Nahidik* and ACES programs.

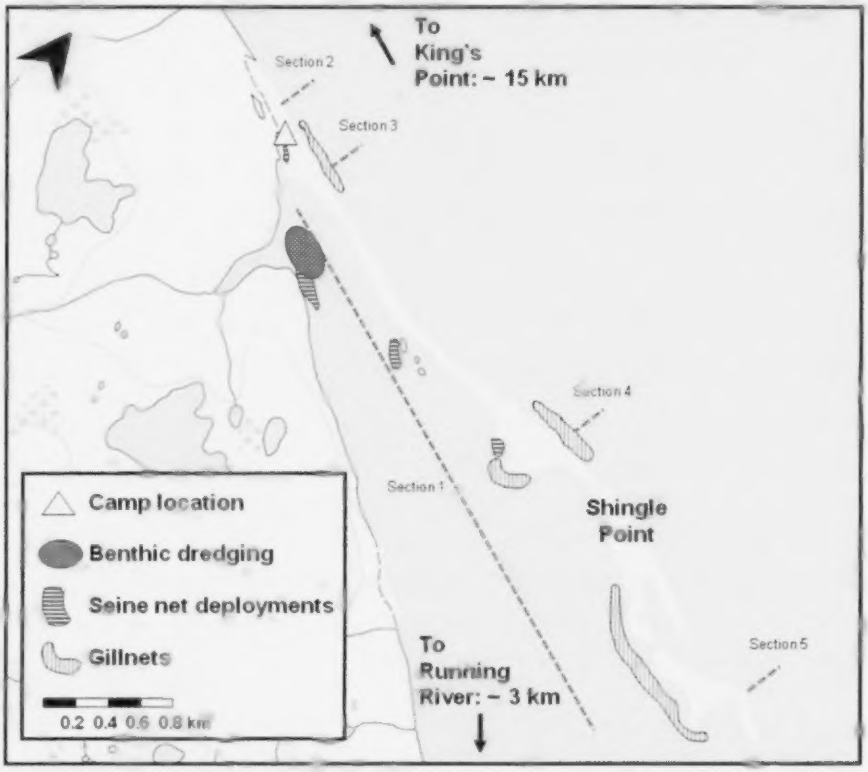


Figure 11. Field camp and sampling locations at Shingle Point during ACES 2011. Primary locations of fishing and benthic sampling and approximate locations of water parameter measurements are shown. Sections indicate the location of selected temperature and salinity distributions.

RESULTS FROM ERI RESEARCH

- Successful field seasons in 2010 and 2011 at Shingle Point (YT) (Figure 11) resulted in the collection of 17 fish species (Table 2). In total, there were approximately 800 specimen collected each year that were immediately frozen for SI and FA sub-sampling. Samples from the 2010 field season have been analysed while samples from 2011 are being analysed at the University of Waterloo (SI) and in-house at the DFO Freshwater Institute (FA).

Table 2: List of fish species collected during the ACES 2011 field work.

Genus and Species	Common name	Abbreviation used
Coregonus autumnalis	Arctic cisco	ARCS
Liopsetta glacialis	Arctic flounder	ARFL
Coregonus nasus	Broad whitefish	BDWT
Lota lota	Burbot	BRBT
Salvelinus malma	Dolly varden char	DVCH
Myoxocephalus quadricornis	Four horn sculpin	FHSC
Esox lucius	Northern pike	NTPK
Stenodus leucichthys	Inconnu	INCO
Coregonus clupeaformis	Lake whitefish	LKWT
Catostomus catostomus	Longnose sucker	LNSC
Coregonus sardinella	Least cisco	LSCS
Clupea pallasii	Pacific herring	PCHR
Oncorhynchus gorbuscha	Pink salmon	PKSM
Osmerus mordax	Rainbow smelt	RBSM
Prosopium cylindraceum	Round whitefish	RDWT
Eleginus gracilis	Saffron cod	SFCD
Platichthys stellatus	Starry flounder	STFL

- Although samples collected during ACES 2011 are still being analysed, results from 2010 are presented. Figure 12 shows results of nitrogen isotope distribution (δN^{15}) amongst various species. This isotope (δN^{15}) is used to define the trophic position of the species – the lower the isotopic signature is, the lower the trophic position (or trophic level) of the species. The range in isotopic values demonstrates the range among species as well as within species. Together with carbon the feeding ecology and niche can be defined.

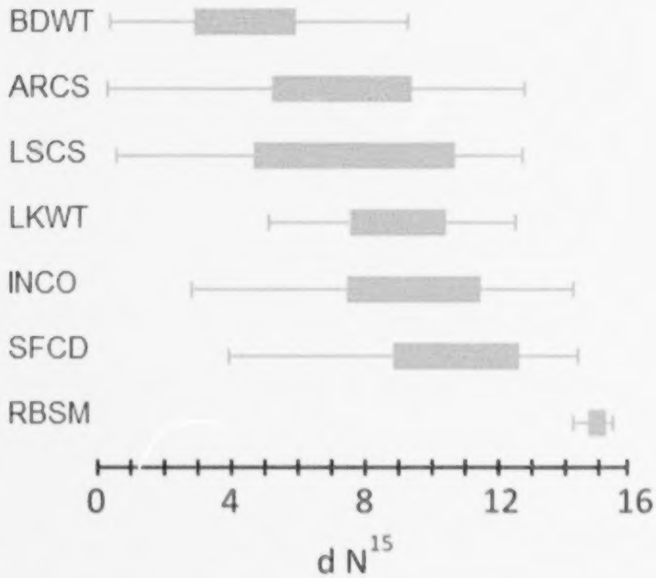


Figure 12: Selected fish species (see the Table for full names) and their nitrogen isotopic signatures. Generally the lower nlitrogen signature the lower is trophic level fish feed at. Here broad Whitefish (BDWT) appears to be omnivorous with a preference towards small crustaceans while Rainbow smelt shows high degree of predatory on other fish.

- To support the data on SI and FA in fishes, other components of the ecosystem were also collected (e.g., benthic invertebrates, zooplankton, phytoplankton). Data obtain from the analysis of these biota will be used as a baseline for establishing the trophic linkages within the ecosystem (Section 4).

- This program partners with Section 4: Understanding fish diets through stable isotope analysis at Phillips Bay. The ACES program is in its infant stages and will take lessons learned from Phillips Bay in regards to the modelling approaches used and applied.

GAPS IDENTIFIED

The ACES program has expanded the *Nahidik* data on fish by adding coastal samples to the previously collected shallow shelf fish and benthic samples. However, our understanding of fish distribution and diets in deeper waters (i.e., >100 m) is still lacking. The upcoming BREA project will sample the offshore fish populations for the first time to

focus on improving our overall understanding of fish ecology. The combination of knowledge from inshore and offshore ecosystems and their linkages are crucial for understanding how the Beaufort Sea ecosystem functions as a whole.

Although, we have collected information on SI and FA signatures from two consecutive sampling seasons, three seasons are needed in order to validate the data statistically. In addition, continued sampling is needed to have more confidence in our baseline values, which feed into other projects such as food web models (Sections 4 and 10).

There is a need for a long-term study in the Beaufort Sea coastal areas that are regarded as sensitive to local disturbances (e.g., contaminants, climatic drivers) and as such can quickly indicate changes in the greater ecosystem. Longer data sets not only provide more confidence in the data trends but also keep the local communities engaged in the process of data collection and lead to better knowledge dissemination (i.e., more successful science reporting to the local communities).

SECTION 4: UNDERSTANDING FISH DIETS THROUGH STABLE ISOTOPE ANALYSIS AT PHILLIPS BAY

BACKGROUND

There are a number of coastal and estuarine fish species in the Beaufort Sea, and understanding interrelationships among species is critical to predicting the effects of anthropogenic stressors and identifying sensitive taxa or trophic guilds. Stable isotope analysis was conducted on samples taken for the Phillips Bay program to establish trophic ecology of coastal and estuarine fishes. The Phillips Bay fish project originated in the 1980s and was repeated in 2007-2008. The site was chosen because of the availability of previously collected data and the ease of continued sampling. Coastal fish sampling eventually expanded to include the ACES program, and similar analyses could be applied to date from ACES and the *Nahidik* program, which focussed on offshore sampling (up to the shelf break) to expand our understanding of fish biology. The objectives of this component of the ERI program were to: i) quantify interrelationships among fishes in the coastal fish community in Phillips Bay (0-20 m depth) using stable isotope analysis; ii) compare stable isotope ratios in selected coastal fishes between 1980s and present; iii) quantify relative use of marine and freshwater environments by anadromous fishes in Phillips Bay; iv) quantify 'isotopic niche' of coastal fish species; and, v) use results from all of the above to identify key indicator species for future monitoring activities.

Fishes captured in Phillips Bay included Cisco (*Coregonus autumnalis*), Arctic flounder (*Liopsetta glacialis*), Starry flounder (*Platichthys stellatus*), Pacific herring (*Clupea pallasii*), Rainbow smelt (*Osmerus mordax)*, Least cisco (*Coregonus sardinella*), Broad whitefish (*Coregonus nasus*), Inconnu (*Stenodus leucichthys*), Fourhorn sculpin (*Myoxocephalus quadricornis*), Lake whitefish (*Coregonus clupeaformis)*, and Saffron cod (*Eleginus gracilis*). Stable isotope analyses were performed on samples collected from each fish to determine trophic level ($\delta^{15}N$; the ratio of ^{15}N to ^{14}N increases with each trophic level), carbon source ($\delta^{13}C$; differentiates between nearshore and offshore sources of production) and marine vs freshwater habitat use ($\delta^{34}S$). Isotopes were

compared among species and time periods using general linear models, and several linear metrics developed specifically for analyses of stable isotope data.

Layman *et al.* (2007) recently proposed several metrics that can be applied to stable isotope data used to quantify food web structure and isotopic niche. The metrics are usually calculated with 2-dimensional data (i.e., biplots of $\delta^{15}N$ and $\delta^{13}C$), but here the metrics were applied to three-dimensional (3-D) data - $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ ratios. The metrics included: i) range of each isotope ratio; ii) mean distance to centroid (in 3-D isotopic space); iii) mean nearest neighbor distance; and, iv) standard deviation of nearest neighbor distance. Range in isotope ratios describes the range of variation along each of the isotopic axes, mean distance to centroid reflects overall spacing within the food web, and mean and standard deviation of nearest neighbor distance indicate how closely and evenly species are packed in three dimensional isotopic space.

RESULTS FROM ERI RESEARCH

Results have been split into 2 general categories: First the 'current' or 'contemporary' data and second, a comparison with historic data (1980s).

Results from Contemporary Data

Results from the 2007-2008 data reveal:

- Delta^{15}N ratios (indicator of trophic position) indicated that this fish community currently spans ~ 2 trophic levels (Figure 13), and that the eleven species fall into 4 groups. Group 1 (green ellipse), consists of a single species, Broad whitefish, which feeds at a lower trophic level than all other fish species. Groups 2 and 3 represent fish that feed in the middle of the food web (red and blue ellipses). Group 4, similar to group 1, also consists of a single species, Fourhorn sculpin (purple ellipse), which feeds at a higher trophic level than all other fishes.

- Delta^{15}N (index of trophic level) ratios were significantly related to fish length, weight, and/or age in 10 of the 11 studied species (the only exception was Lake whitefish, a benthic feeder). Relationships between δ^{15}N and length also differed significantly among species. This indicated that ontogenetic shifts in feeding are more dramatic for some species than for others. It also means that future sampling should include as large a size range in fish as possible, as this will enable us to account for effects of life history stage when comparing trophic ecology among species.

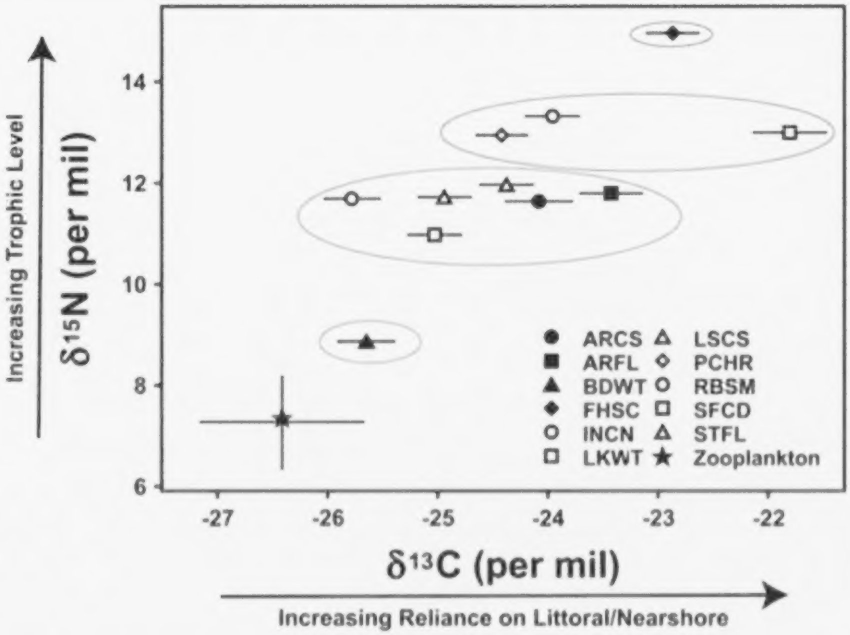


Figure 13. Least squares mean (LSmean) δ15N and δ13C (+ SE) ratios for each fish species and zooplankton sampled in Phillips Bay. LSmeans were calculated at a fish length of 250 mm after among-year variation was accounted for in a mixed model. Group 1 = green; Group 2 = blue; Group 3 = red; Group 4 = pink.

- Delta^{13}C ratios (index of benthic vs. pelagic feeding) were extremely variable within species (large error bars on the X-axis, Figure 13). The use of δ^{13}C in future monitoring therefore lies in its complementarity with δ^{15}N; it should not be used as a stand-along indicator.

Comparisons Between Contemporary and Historic Data

Species-specific comparisons between ‘current’ (2007-2008) and ‘historic’ (1984-1986, depending on the species) time periods were possible for Arctic cisco, Broad whitefish, Lake whitefish, and Least cisco, and include data on $\delta^{15}N$, $\delta^{34}S$, $\delta^{13}C$, fish size, and C:N ratios (indicator of lipid).

- **Arctic cisco:** $\delta^{13}C$ ratios decreased significantly between 1984 and 2007-2008, indicating Arctic cisco may have shifted to feed on more pelagic (vs. benthic/littoral) prey. To investigate whether the observed change in $\delta^{13}C$ could be attributed to increased lipid contents (fat storage in fish), $\delta^{13}C$ ratios were compared to C:N (or carbon to nitrogen ratios (C:N ratios; are an indicator of lipid content). These two variables were significantly related for Arctic cisco, with C:N increasing significantly from 1984 to 2007-2008. This explains the observed change in $\delta^{13}C$, as there is a known negative relationship between $\delta^{13}C$ and lipid, with organisms having more lipids have lower $\delta^{13}C$. The reason for the increase in lipid in Arctic cisco is unknown, but likely reflects greater food availability and/or better growth conditions (e.g., optimal temperature, decreased competition).

- **Lake whitefish**: $\delta^{34}S$ ratios, which can be used to differentiate between marine and freshwater habitat use, increased significantly between 1986 and 2007-2008. It therefore appears that Lake whitefish have shifted their diet toward greater reliance on marine prey items (marine derived prey has higher $\delta^{34}S$ values). Lipid stores, as indicated by C:N, also increased significantly during this time period. Thus, it appears that increased reliance on marine prey has resulted in better growth conditions (perhaps due to lower foraging costs or greater energy content in marine prey).

- Relative use of marine and freshwater environments by anadromous (i.e., sea-run) fish species in Philips Bay was assessed by applying Bayesian-based mixing models to $\delta^{34}S$ ratios. These preliminary analyses indicate that Arctic

cisco, Least cisco, Fourhorn sculpin, and Rainbow smelt rely heavily (>80%) on marine-derived prey (Table 3). Inconnu and Lake whitefish also obtain the majority of their prey (> 70%) from the marine environment, whereas both freshwater and marine environments appear to be important foraging areas for Broad whitefish (Table 3). This means that Broad whitefish are likely more sensitive to climate-induced changes in freshwater discharge/climate-induced barriers to migration, although this will be highly dependent on how seasonality of flow is affected.

Table 3: Approximate proportional contributions of marine and freshwater-derived prey to anadromous fishes in Phillips Bay as calculated through $\delta^{34}S$ Bayesian mixing models.

	Approximate proportional reliance on marine-derived prey	Approximate proportional reliance on freshwater-derived prey
Arctic cisco	0.90	0.1
Broad whitefish	0.45	0.55
Inconnu	0.72	0.18
Lake whitefish	0.70	0.30
Least cisco	0.84	0.16
Fourhorn sculpin	0.85	0.15
Rainbow smelt	0.84	0.16

Isotopic niche space of coastal fishes

- Close investigation of Table 4 reveals several patterns and groupings of fish. Both Broad whitefish and Lake whitefish show considerable range in isotope ratios. This is particularly apparent for $\delta^{34}S$, which ranges more than 30‰ among Broad whitefish and nearly 20‰ among Lake whitefish. These two species also show high mean nearest neighbour distance and standard deviation of nearest neighbour distance, which indicates substantial inter-individual differences in feeding. It is likely that most of this variation stems from variability in migratory history and use of freshwater vs. marine food sources, but this requires further investigation.

- Inconnu, Least cisco, and Fourhorn sculpin are consistently intermediate in their isotope metrics (Table 4). All of these species are anadromous, appear to use a variety of both freshwater and marine resources (based on mid-range $\delta^{34}S$ values), and display considerable inter-individual differences in feeding (mean and standard deviation of nearest neighbor distance).

- Considering all metrics together, Arctic flounder, Starry flounder, and Arctic cisco (Table 4) appear to feed on a more narrow range of prey items than Inconnu, Least cisco, Fourhorn sculpin, and the whitefish species, but on a wider range of prey items than Pacific herring, Saffron cod, and Rainbow smelt. The flounder species are not anadromous, therefore it is not surprising that they appear to use a narrower range of resources than the coregonid species and sculpin described above, which do feed in both marine and freshwater habitats. They do show a wider range in $\delta^{34}S$ than would be expected for a fully marine species, this likely reflects variability in use of the river mouth/lower salinity waters. Further research, including data for isotope ratios from both freshwater and marine invertebrates, is needed to confirm this.

- Pacific herring, Saffron cod, and Rainbow smelt display the lowest values in most isotope metrics (Table 4). This is not surprising for Pacific herring and Saffron cod, which are both fully marine species (i.e., not anadromous). Rainbow smelt can be anadromous and they appear to feed in a broader range of salinities (indicated by a higher $\delta^{34}S$) than either Pacific herring or Saffron cod, but they also appear to be very closely and evenly packed in isotope space (mean nearest neighbor and standard deviation of nearest neighbour). This indicates that there may be relatively small inter-individual differences in feeding.

Table 4: Isotope-based metrics for each species and for the whole fish community.

	$\delta^{15}N$ range (‰)[a]	$\delta^{13}C$ range (‰)	$\delta^{34}S$ range (‰)	Distance to centroid	Mean nearest neighbour distance	Standard deviation of nearest neighbour distance
Whole fish food web	6.10	4.06	19.5	4.27	2.75	2.02
Arctic cisco	2.87	4.89	6.10	1.51	0.44	0.28
Arctic flounder	1.94	3.69	12.9	2.50	0.48	0.30
Broad whitefish	5.79	7.68	31.5	8.60	1.18	0.61
Fourhorn sculpin	3.93	4.76	19.6	1.82	0.50	0.36
Inconnu	3.42	5.46	14.7	2.67	0.64	0.44
Lake whitefish	3.77	6.67	19.6	3.77	0.93	0.53
Least cisco	4.15	5.67	14.9	2.54	0.65	0.46
Pacific herring	1.24	2.47	2.56	0.68	0.23	0.15
Rainbow smelt	2.39	2.65	5.55	1.10	0.35	0.25
Saffron cod	3.34	3.60	4.01	1.15	0.42	0.24
Starry flounder	2.24	2.98	16.51	2.30	0.52	0.29

Indicator Species

Based on the analysis presented, potential indicator species were selected based on numerous criteria: i) represent different isotopic values in the fish community (Figure 13); ii) are more likely to show changes over time; iii) represent a range of freshwater vs. marine habitat use (3); and, iv) represent a range of values in isotopic niche space (4). Based on the available data, the four species recommended as potential indicators are:

1. **Broad whitefish** – Broad whitefish currently represent the lowest trophic level in the fish food web, occupy the largest isotopic niche, and use freshwater-derived prey more than any other anadromous species. If freshwater inputs to Phillips Bay decline because of changing river flow, Broad whitefish is likely to show changes in trophic ecology.

2. **Lake whitefish** – Lake whitefish appear to have more lipid stores and use the marine environment to a greater extent than they did 30 years ago. Lake whitefish also represent a species with intermediate use of both marine- and freshwater-derived prey (Table 3), and an intermediate trophic level (Figure 13).

3. **Arctic cisco** - Arctic cisco were chosen as an indicator species because there have been temporal changes in lipid over the last 30 years, and because this

species has the most complete dataset. Ideally, Fourhorn sculpin would have been chosen as the third indicator species, as it occupies a unique trophic level (Figure 13); however, Fourhorn sculpin can be difficult to capture.

4. **Pacific herring** – Pacific herring represent a species that is easy to capture and fully marine. Pacific herring also occupy the smallest isotopic niche space in the coastal fish community, and feed at a higher trophic level than Arctic cisco, Lake whitefish, or Broad whitefish.

GAPS IDENTIFIED

Most of the data gaps identified are a result of incomplete integration between independent programs, and/or individual researchers sampling certain components of the food web. For stable isotope data to be used to their fullest extent, all levels of the food web must be sampled at the same time, and in the same place. This includes primary producers (e.g., periphyton, phytoplankton), primary consumers (e.g., benthic invertebrates, zooplankton), and fishes. Ideally, all three isotopes (C,N,S) should be analysed. It is imperative that complete fish data be collected, including length and weight (at minimum), and age if possible. The most common data gap encountered was a lack of invertebrate data. Without invertebrate 'baseline' data, it is impossible to compare isotope ratios between sites. Hence, this analysis was limited to Phillips Bay, which served only as a representative coastal ecosystem.

In many cases, individual researchers had each sampled one component of the food web at slightly different sites and/or depths. While this no doubt met the objectives of smaller, more specialized programs, integrating these data for community and ecosystem-scale analyses was extremely difficult. In many cases, depth data were not recorded, and sites were called different names by different researchers. As stated above, this resulted in the analysis being confined to Phillips Bay. As well, there was no central repository for data. For future ecosystem scale projects, formalizing data sharing and data management agreements before sampling begins is essential.

SECTION 5: IDENTIFICATION OF EMERGING INFECTIOUS DISEASE THREATS TO THE MARINE MAMMALS OF THE BEAUFORT SEA.

BACKGROUND

The ERI synthesis report from the 2010 workshop on priorities in the Beaufort Sea LOMA documents the need for the continued surveillance for infectious diseases in marine mammals in this environmentally important management area (Wieckowski *et al.* 2012). This project builds on disease surveillance data for distemper and brucellosis that has been collected since the early 1990s in both ringed seals and beluga. Distemper can cause severe acute disease in seals with mortalities approaching 50% (Jensen *et al.* 2002). Cetacean distemper is known to occur in cetaceans in southern regions inhabiting both the Atlantic and Pacific oceans (Saliki *et al.* 2002). The effects of climate change may make it more likely for this disease to move northwards. As marine mammal distributions change, transmission of a potent pathogen into a susceptible population of arctic whales would be catastrophic.

In July 2011, reports from Alaskan seal researchers indicated that a number of sick and dying seals were being identified from the North Slope of Alaska. Subsequently, reports of sick/dying seals were reported from Tuktoyaktuk, Paulatuk and Sachs Harbour (NT). Hunter observations from communities in Nunavut and necropsy results from a few submitted seals indicate the disease has spread to ringed seals all across Arctic Canada. The cause and impact on the seal population is still presently unknown, however DFO is working with Alaskan and US officials to co-ordinate the investigation and identify the causative agent responsible for this disease. As of fall 2013, no definitive cause of the disease has been identified but a few sporadic cases continue to be identified in seals from Alaska and the ISR (the most recent being a ringed seal from Sachs Harbour in the fall of 2013). These findings indicate the disease is still circulating among arctic seals but at a much lower attack rate. Recently, it has been shown that other potentially zoonotic diseases (infectious diseases transmitted between species) have been discovered in arctic seals. Toxoplasmosis is a parasitic disease usually

associated with contact with infected cat feces, but this disease is becoming increasingly important among Canadians living in the North. Samples from Canadian Arctic hunters were identified as positive for *Toxoplasma gondii*, which can be spread to humans through the consumption of raw seal meat (Simon *et al.* 2011). Efforts are underway to test for toxoplasma in seals harvested from Ulukhaktok using polymerase chain reaction (PCR) testing, the same approach used by (Simon *et al.* 2011).

RESULTS FROM ERI RESEARCH

- Table 5 indicates the number of seals that have been infected with phocine distemper (PDV) and have survived the infection and subsequently have immunological protection (antibodies) from future infection. A relatively high number of positive animals from both locations in 1994-94 indicate a recent disease outbreak. The absence of PDV antibodies (low prevalence in testing positives) from 2009-10 indicate that seals from both areas are at risk for infection and disease. Phocine distemper is a virus known to occur in sea otters from Alaska and transmission to seals is highly likely since they are sympatric species and commonly come into contact with one another.

Table 5: Prevalence of phocine distemper (PDV) neutralizing antibodies in ringed seals harvested in two communities in the ISR.

Sampling Location	Year	Prevalence
Holman	1993	8/31 (25.6%)
	1994	0/3
Paulatuk	1993	8/31 (25.6%)
	1994	26/38 (68.4%)
Holman	1993	2/29 (14.5%)
	1994	0/30

- Serology results from hunter-harvested beluga (hundreds of samples have been tested since the 1980s) indicate that there is no protective herd immunity (antibodies) to distemper (also known as morbillivirus or CeMv) in beluga. Therefore, arctic beluga have no ability to fight off cetacean morbillivirus (CeMV) once it is introduced into these populations. If an outbreak occurs, a large scale epizootic (widespread outbreak within a species) is expected. Cetacean species

infected with CeMV have been identified in southern waters of both the Atlantic and Pacific oceans. As arctic oceans warm, it is more likely that infected cetaceans will migrate further north and come into contact with immunologically naïve populations of arctic cetaceans.

- Isolation of unidentified pathogens affecting seals and walruses across Alaska and Canada commencing in 2011 and continuing until the present remains a high priority for both Canada and the US. Though the primary cause is still unknown, a new virus remains the leading suspect. ERI funds were used to attempt viral isolation from both sick walruses and seals from Alaska, and this work continues. Community input from hunters has confirmed that the same set of symptoms seen in seals from Alaska is also being seen in seals from the communities in the Beaufort Sea.

- Recent collaborative investigations between researchers from Alaska, Quebec and DFO regarding beluga from Bristol Bay (Alaska) and the St. Lawrence River (Canada) have determined that alphaherpes virus infection maybe widespread among these populations. The virus has been isolated from three animals originating from Alaska and Canada in the Winnipeg lab and genetic sequencing is underway to determine their relationship to other cetacean herpes viruses.

- In conjunction with researchers from the school of veterinary medicine at the University of Montreal, work is underway to sequence two gammherpesviruses isolated from ringed seals harvested from Ulukhaktok from 2003 and 2004. Herpesvirus infection in seals is fairly common but the morbidity and mortality as a result of infection is not well known.

GAPS IDENTIFIED

Firstly, better methodology is needed in order to identify, obtain, transport, and sample sick or diseased animals back to the laboratories safely and within a timely manner. At present the majority of (good) samples being tested are from Alaska, where samples

are taken from either live caught, freshly dead animals, or flash frozen at minus 80°C and immediately transported in dry shippers containing liquid nitrogen as the refrigerant. Samples handled in this manner are more likely to yield virus isolates of interest. In comparison, Canadian samples are currently held at minus 20°C degrees for months at a time before being shipped to diagnostic laboratories, and are of little use for identifying viruses that may be present in these animals. Next, new marine mammal cell lines are needed to isolate and study emerging viral pathogens. Cell lines are cells derived from animals and are propagated outside their bodies *in vitro*. Since viruses need to grow and reproduce inside living cells, and seal and cetacean cells offer the best chance of isolating viruses specific to these animals, a more co-ordinated effort is needed to develop this important and necessary methodology. Finally, the relationship between climate change, seal and beluga health and emergence of potentially devastating emerging pathogens needs to be better understood in order that these effects can be modelled accurately.

SECTION 6: DISTRUBUTION, MOVEMENTS, AND BEHAVIOUR OF BOWHEAD WHALES, BELUGA WHALES, AND RINGED SEALS IN THE SOUTH EAST BEAUFORT SEA AND AMUNDSEN GULF DURING OPEN WATER PERIOD, 2007-2010

BACKGROUND

Beluga and bowhead whales are seasonal migrants to Canada's Western Arctic, occupying summer range in the southeastern Beaufort Sea and Amundsen Gulf within the Inuvialuit Settlement Region. Both whale species travel through United States (Alaska) and Russian offshore waters, which include migration routes and over-wintering areas for both species. Ringed seals are year-round residents, and the most abundant and widespread marine mammal in the Arctic. All three species are important in the subsistence harvests of the Inuvialuit, the Inupiat (from Alaska) and their ancestors.

The purpose of this project was to document the distribution and movements of marine mammals in the Beaufort Sea during the open water period. Bowhead whales and ringed seals were tagged with satellite transmitters to track their movements and identify key habitats. In addition, aerial surveys were conducted to obtain a regional overview on distribution patterns for beluga and bowhead whales. Throughout this project, 21 bowhead whales (Figure 14) and nine ringed seals were tagged and tracked in Canada's Western Arctic. A total of four seasons of aerial surveys were flown (25,000 km^2 including the Beaufort Sea from the US border, continental shelf to the shelf break, the west coast of Banks Island, western Amundsen Gulf) with 1500+ beluga and 334 bowheads sighted on-transect in the offshore areas. Analysis and publication of results from all aspects was initiated in 2009, and have continued as time and resources permit during 2010 -2012.

RESULTS FROM ERI RESEARCH

- Bowhead whales were observed to aggregate in the southeast Beaufort Sea each summer to feed, with an estimated 50% of the regional population being present at any one time between early August and mid-September.

- Each summer bowheads use 4-5 different feeding areas, although not every area is used each year. These sites are attractive to bowheads due to oceanographic conditions, which favour the production and concentration of zooplankton, their main prey. Bowhead visits to feeding areas are highly variable among individuals, lasting from days, to weeks, to months. The Amundsen Gulf was found to be an important feeding and staging area for bowheads in late May.

Figure 14: Bowhead tracks between August 20-30, 2012 for 12 whales, each represented with a different arrow. MODIS ice image (dated August 22) courtesy of NASA (http://rapidfire.sci.gsfc.nasa.gov). For more information visit: http//www.wildlife.alaska.gov/index.cfm?=marinemammals.bowhead

- The number of belugas observed during aerial surveys was stable for 2007, 2008 and 2009. The estimate of the beluga population was three times higher than the estimates from surveys in 1982, 1984 and 1985, covering the same area (Figure 15).

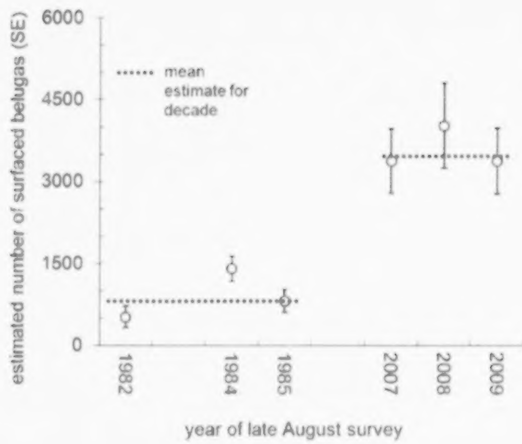


Figure 15: The estimated number of belugas based on surveys occurring in late August in the Beaufort Sea. (Harwood *et al.* 2013)

- Population growth alone is probably not sufficient to explain the changes observed in relative abundance of belugas between decades, but could be in part, responsible in some unknown proportion. The most plausible explanation for the apparent increase in belugas is that the offshore became more attractive to belugas in the 2000s, either because of a decrease in the intensity or extent of industrial activity, climate warming related changes to the marine ecosystem, or both.

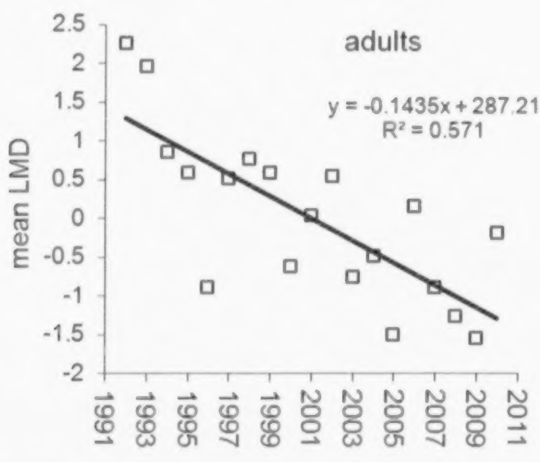


Figure 16: Mean body condition (Length-Mass-Blubber Depth) of adult ringed seals sampling during June near Ulukhaktok, 1992-2010 (Harwood *et al.* 2012).

- Immediately following the breakup of fast ice in spring, adult and subadult ringed seals make extensive summer feeding forays (1000s of kms), presumably to summer feeding habitats. The subadults do not usually return, dispersing prior to freeze-up and overwintering in distant locations. In contrast, adults return to the core breeding habitats as they are constrained by the need to establish territories and build lairs. They return just prior to freeze up, and remain in their established territories throughout the winter and spring.

- The size of the summer range used by ringed seals is about 10 times larger than the size of the range they use in winter. In heavy ice years, the winter range is more restricted, limited to a few hundred kilometres or less.

- There is a statistically significant trend of declining body condition in ringed seals in the eastern Amundsen Gulf over the past two decades. The mean annual body condition of adults and subadults was negatively correlated with the timing of fast ice clearance in spring, most obvious during extreme ice years in all sex/age groupings, and statistically significant for subadults. Also, in heavy ice years there was failure of reproduction, coinciding with the lowest body condition values. The seal population in this core habitat appears to have recovered from natural and extreme-year fluctuations over the past four decades. However, the possible magnified effects of consecutive extreme ice year events, compounded by the simultaneous occurrence of the temporal decline in seal body condition is of particular concern for the ringed seal population.

GAPS IDENTIFIED

The documented long-term decline in ringed seal body condition over the past two decades is of concern, and warrants further study and monitoring. The timing of the study implicates a shift in winter diets while the decline in body condition implicates a reduction in prey quality or quantity. In addition, there has been a less obvious decline in beluga whale body condition during the same period. The most promising technique to study such changes is to continue monitoring body condition and include measures of

diet (e.g., stable isotopes, fatty acids) to identify links in environmental conditions and health of belugas and seals. Further to this, gaps continue to remain on the effect industry has on marine mammals in the area. For example, future studies could focus on using bowhead whale satellite telemetry data to evaluate the short-term responses of tagged animals to industry activities that they encounter in the Beaufort Sea, in order to better assess and monitor their responses.

SECTION 7: BELUGA HEALTH PROGRAM

BACKGROUND

Beluga whales are high trophic level consumers, (Hobson *et al.* 2002) just below top predators. Their high trophic level combined with a long lifespan, render them vulnerable to contaminants such as PCBs, which are known to persist and accumulate in fat reserves (blubber layers) over time and biomagnify up food webs. Persistent organic pollutants (POPs) such as PCBs are known to be immunotoxic, effect endocrine and reproductive systems, as well as demonstrate genotoxic impacts (Brouwer *et al.*, 1989, Safe 1994, Ross *et al.*, 1996, Tabuchi *et al.*, 2006). Concerns regarding contaminants in the Canadian Arctic emanate from the potential health impacts to humans with subsistence-based diets containing beluga. Technical and logistical challenges have generally prevented health assessments in Arctic marine mammals, but new and emerging technologies are providing an opportunity to build on past efforts and shed light on the impact of contaminants on higher trophic level consumers.

Every summer thousands of beluga whales from the eastern Beaufort Sea population arrive in the Mackenzie River estuary, representing one of the largest summering aggregations of beluga whales (Fraker *et al.* 1979). The summer harvest of Beaufort Sea beluga whales by communities of the Inuvialuit Settlement Region (Northwest Territories, Canada) is an important component of the Inuvialuit subsistence lifestyle (Usher 2002). A beluga whale harvest monitoring program has been in place since the 1980s and has enabled the collection of contaminant and population information. Trends in contaminants raised concern among communities and the general health and well-being of the beluga population was questioned. While the beluga population appeared healthy it was recognized that the region is undergoing changes such as climate change and increased interest oil and gas development. As such, a beluga health program was developed to characterize current beluga health and assess if present contaminant levels were having any effect on beluga health, while considering the potential for future climate change effects on beluga.

A changing climate and its cascading effects on sea ice cover, food web productivity, beluga distribution and feeding ecology may change the course of contaminant fate in the Arctic environment, as well as the condition and health of beluga. Climate change has the potential to confound our understanding of mechanistic linkages between contaminant exposure and health effects, but may also have serious implications for the health of beluga whale populations. The region in which this population aggregates for the summer is of interest for oil and gas development. Thus, both current and future changes will likely impose multiple stressors to the beluga whale population. This program is designed to characterize diet, contaminant exposure, condition and nutritional status of beluga to begin identifying linkages between climate, contaminants and health of beluga.

RESULTS FROM ERI RESEARCH

In partnership with the hunters from Tuktoyaktuk, NWT, beluga whales were sampled from 2007 to 2011, with the majority being adult males. Analyses are still being completed, however preliminary results are broken into three main categories: (1) contaminants and how they relate to beluga feeding, (2) metabolism of contaminants, and (3) the toxicity of contaminants.

Contaminants and feeding relations

- Earlier evidence of a size-based segregation of Beaufort Sea beluga whales (Loseto *et al.*, 2006) and impacts on diet and mercury levels (Loseto *et al.*, 2008, 2009) has been further supported by a more recent assessment of contaminants such as PCB and PBDE concentrations and patterns in Beaufort Sea beluga whales.

- Concentrations of PCBs did not differ among the four years sampled, with females having lower concentrations than males. This is typical because females release or offload their contaminant burden during birth to their young.

- The concentrations of PBDEs were an order of magnitude lower than PCBs as they have not been in the environment as long as PCBs. However, unlike PCBs, mean concentrations differed among years.

- Examining males only, the age of beluga whales did not show a significant relationship with PCB or PBDE concentrations. Rather, beluga length was positively related to PCBs for all years combined ($r = 0.6$, $p < 0.0001$). However, among individual years, belugas collected in 2008 did not maintain a significant length relationship with PCBs. Similarly, length was positively related to PBDEs with all years combined ($r = 0.3$, $p = 0.04$).

- Fatty acid signatures provided insight into feeding ecology as it is related to length (Loseto et al., 2009) and contaminant concentrations in beluga. Fatty acid data was summarized for the inner layer of beluga blubber using a principle component analysis (PCA) with 38 dietary fatty acids. The fatty acid PCA scores were used to evaluate drivers of diet such as length of whale (a proxy for habitat use)[1] and diet, as well as PCB and PBDE concentrations. With the exception of 2008, the PCA scores on the first axis (PC1) were significantly related to length, as well as to PCBs and PBDEs in all four years ($p < 0.01$). These results demonstrate the link between recent diet and PCB concentrations. The lack of a trend for beluga length vs PCBs in 2008 suggest that beluga may not be feeding as previously found, where length drove foraging behaviour. However, their diet was still associated with contaminant concentrations. This difference may in part be due to an inter-annual change in feeding ecology, as the whales alter foraging behaviour with changing ice conditions.

[1] Males segregate in relation to size and result in different dietary signatures (Loseto *et al.*, 2006; 2009).

Metabolism

- The concentration and pattern (i.e. expression of individual congeners as a percent of the total) of PCBs and PBDEs congeners were examined in beluga and their prey items in order to determine the major factors influencing contaminant exposure. In examining the potential prey items, there was an apparent association between observed PCB patterns in beluga with different habitat uses. For example, prey inhabiting marine/pelagic areas had different PCB congener patterns than prey from nearshore/benthic areas. Therefore, beluga feeding ecology could explain the observed patterns for PCBs and PBDEs. While the total PCB concentrations varied in beluga with different habitat uses (offshore vs nearshore), the PCB congener patterns (expression of individual congeners as a percent of the total) remained consistent. Thus, these results suggest that the PCB and PBDE patterns in wild whales were primarily driven by selective metabolism of congeners based on molecular structure and activity. These findings were supported by analysis of captive aquarium beluga, and show that potential diet changes associated with a changing climate will have implications on contaminant concentrations, but that congener patterns will remain relatively unchanged.

Toxicity: Genomic indicators

- As a potential means to assess early impacts of contaminants, a new genomic approach was used to consider impacts of contaminants at the molecular level. These techniques, such as quantitative polymerase chain reaction (qPCR), offer opportunities to detect changes in targeted gene mRNA transcripts. We developed new beluga-specific tools to investigate the potential impacts of PCBs and PBDEs on gene expression in beluga blubber, skin, liver, and muscle samples (n= 54; collected 2008 to 2010).

- While beluga PCB and PBDE concentrations were in the low to moderate range compared to other populations (e.g., St. Lawrence Beluga whales see Muir *et al.*

(1990)), results revealed that PCB levels were high enough to trigger metabolizing enzymes. The enzymes Cyp1A (cytochrome P450, family 1, member A) and AhR (aryl hydrocarbon receptor) had mRNA expressions that increased as PCB levels increased in whale blubber samples. The extent to which increased PCB levels impacts the population as a whole remains unclear. Eleven other genes related to metabolism, growth and nutrition did not show differences in mRNA expression in relation or response to contaminants, diet or biometrics.

Immunotoxicity: Invitro

- While mercury (Hg) is known to be toxic to mammals in general, little is known about its effects in beluga whales. Since dose-response studies are not practical in beluga whales, we developed a non-invasive strategy to evaluate the toxicity of Hg isolated from whole blood in live captive whales at the Vancouver Aquarium. Here we; (1) evaluated the effects of inorganic Hg and organic Hg on the function of lymphocytes (white blood cells) in beluga blood; (2) characterized the potential protective effects of selenium on cell growth using Hg treated white blood cells; and (3) compared these dose-dependent effects to measurements of blood Hg in free-ranging samples collected from beluga whales in the western Canadian Arctic (Frouin *et al.* 2012).

- White blood cell growth (immune response) was reduced following exposure to 1μM of inorganic mercury and 0.33μM of organic mercury. The concurrent exposure of Se provided a degree of protection against the highest concentrations of inorganic Hg (3.33 and 10μM) or organic Hg (10μM). Current Hg levels in free-ranging beluga whales from the Arctic fall into the range of levels that impacted white blood cell growth in our study, highlighting the potential for effects of Hg on immune system function and disease resistance in free-ranging beluga whales. Mercury levels measured in a variety of wild cetacean populations are presented alongside thresholds identified in captive studies for different immune responses in Figure 17.

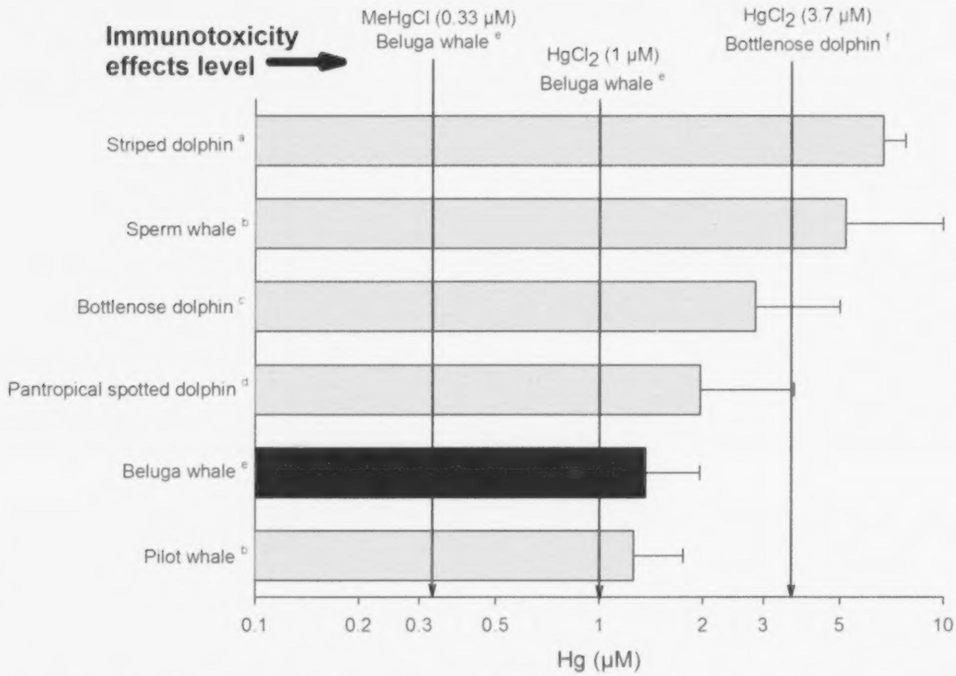


Figure 17: Hg concentrations (mean ± SD) in blood of different whale species (bars) and lowest concentrations of MeHgCl or HgCl2 causing a decrease in white blood cells and immune response (solid lines). Data from multiple studies summarized in Frouin *et al.* (2012)

GAPS IDENTIFIED

One of the largest gaps that still remains is a full seasonal understanding of beluga habitat use that specifically extends into their wintering range, the Bering Sea. For example, resource use in the Bering Sea and how changes in that ecosystem might impact this population is poorly understood. Therefore, indicators are needed to assess how drivers in the Bering Sea are linked to indicators (e.g., blubber thickness) taken from whales sampled in summer in the Beaufort Sea. Understanding the seasonal and spatial relations of beluga habitat use and how it relates to health are key when providing advice to decision makers. Understanding the spatial/temporal use of resources (i.e., diet quality/quantity, habitat features) in context with life history stages will help with future projections and scenarios to consider cumulative impacts.

In addition, another large gap is the quantitative knowledge on stressor effects and how it varies for size, sex and age. While the invitro immunotoxicology work offers quantitative values, it is important to recognize that the extrapolation to wild populations is sometimes difficult. The genomic tools using mRNA described above are a step in the right direction toward developing thresholds for effects. More work is needed on other populations such as the St. Lawrence estuary population to act as a “highly” stressed population to develop thresholds.

Lastly, the gap of how to integrate the health data with the local/traditional knowledge remains one that requires attention. Some small steps have been made to address this gap over the last few years, but more is needed. This will ultimately help to piece together a more holistic view of beluga health and how it relates to the communities who rely on this resource.

SECTION 8: GENETIC MONITORING AND CONSERVATION OF BELUGA WHALES (*Delphinapterus leucas*) IN THE WESTERN CANADIAN ARCTIC

BACKGROUND

The areas used by summer aggregations of beluga whales in the Mackenzie River Delta (Shallow Bay, east Mackenzie Bay and Kugmallit Bay) have been designated a Marine Protected Area (MPA) within the Beaufort Sea Large Ocean Management Area (LOMA). Monitoring indicators for the TN MPA conservation objective identified, under the biodiversity theme, the maintenance of genetic fitness and integrity of beluga assemblages. Genetic diversity is a key factor for the long-term survival of animal populations. When it becomes reduced, negative impacts from the environment on health and reproductive success can be magnified. Understanding the patterns of genetic diversity in beluga assemblages in the TN MPA and adjacent areas will provide information for the eastern Beaufort Sea beluga stock. One strategy used to monitor this indicator is use of a variety of approaches for understanding genetic patterns. Combining the use of kinship-based and population-based inference methods to evaluate genetic diversity can reveal population structure at a finer level of resolution, especially for populations where genetic divergence is low. These types of complementary analyses can also be used to examine possible social structure, and allow us to better understand spatial and temporal influences on range patterns of individual beluga and larger communities of belugas.

Some work was done in the early 1990s using population-based inference to examine broad patterns of genetic stock structure in North American beluga. This work was able to define the Mackenzie Delta summering beluga as a different stock compared to samples examined from 2 locations in Alaska (Norton Sound and Point Lay). The Mackenzie Delta belugas were differentiated based on mitochondrial DNA (mtDNA) haplotypes, which are inherited from a mother and can be used to trace maternal lineage. Nuclear DNA microsatellites supported the hypothesis that these samples all belonged to the same breeding population.

The goal of this study was to increase the amount of genetic information for belugas in this stock and to use new kinship-based methods (i.e., looking at patterns of related individuals in groups of whales) to have more power investigating the amount of genetic structure in beluga aggregations in the Beaufort Sea. This study also expands the geographic scope and time series of previous sampes analysed with genetic markers, and these data will be used to assess the potential for genetic monitoring of belugas in the TN MPA, the Beaufort Sea LOMA, and in relation to Alaskan and Russian beluga whales.

With a large dataset, all samples will be examined for data quality and assurance and any sample with less than 80% of full genotype will be re-analysed and possibly excluded from the data analyses. Initial analyses have been completed, although results do not include the complete data set and should be considered preliminary at this stage.

RESULTS FROM ERI RESEARCH

Approximately 850 tissue samples were analysed using mtDNA sequencing and 17 microsatellite loci. An additional 350 samples were collected from archived jaws sampled during beluga harvest monitoring programs from 1980 to present. Therefore, in the final dataset, 1200 samples are from beluga within the ISR and an additional 140 samples belong to an outgroup of St. Lawrence River beluga (Quebec). Samples from the ISR locations had a strong male bias (overall, 81% of samples were male). Samples from the St. Lawrence River were 46% male and 54% female. Overall, different summer aggregations of beluga whales in the Beaufort Sea were not differentiated on the basis of mitochondrial DNA haplotypes (with the exception of Shingle Point) (Figure 18). Future work will examine temporal trends of haplotypes at each location.

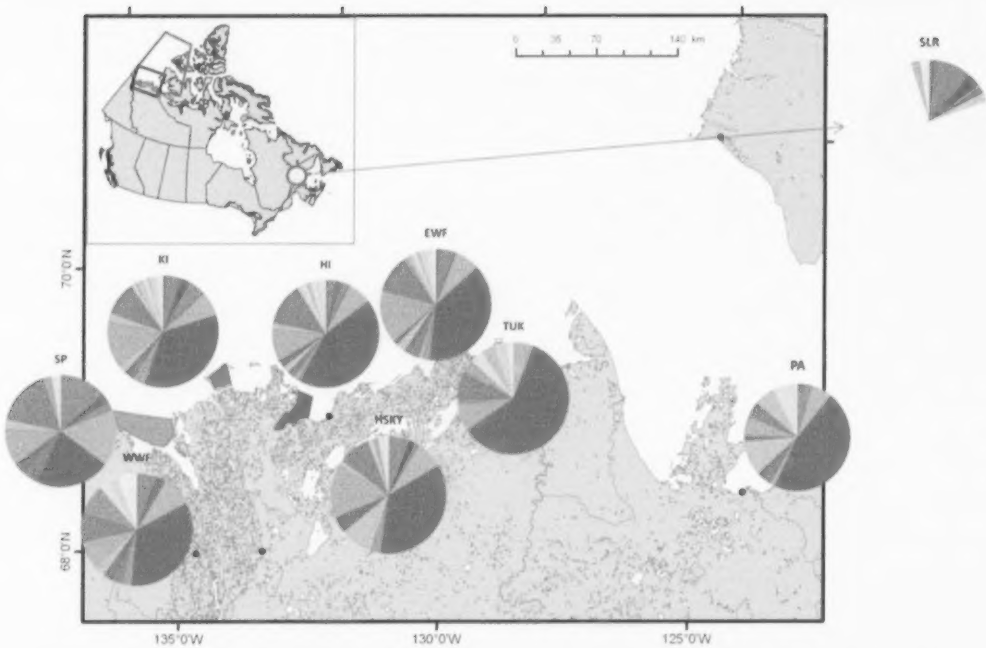


Figure 18: Distribution of mitochondrial DNA haplotypes in beluga samples from different locations: Shingle Point (SP), Kendal Island (KI), west Whitefish (WWF), Hendrickson Island (HI) Husky Lakes (HSKY), East Whitefish (EWF), Tuktoyaktuk (TUK), Paulatuk (PA), and St Lawrence (SLR) for reference. Each coloured slice of the pie graphs represents a different haplotype.

- Preliminary analyses of the nuclear DNA genetics data using kinship-based methods suggest that in some areas of the Beaufort Sea, beluga aggregations are composed of related animals (e.g., Hendrickson Island, Kendall Island). This may be an indication that the use of some areas may be a learned (from a kingroup) or social behaviour that is different than maternally-directed site philopatry.

- The genetic relationships of belugas sampled from Husky Lakes suggests that animals moving into the Husky Lakes area have group composition and group relatedness that are different from year to year and that these animals differ from those that are harvested at camps along the Beaufort coast (e.g., Hendrickson Island, Kendall Island).

GAPS IDENTIFIED

The most significant gap for most population genetics research, and certainly for a genetic monitoring program, is the sampling design. Samples collected from harvest monitoring programs and other opportunistic sampling are cost effective, but can introduce sampling bias. From a genetics perspective, this may not a representative sample of the biological population, as harvested whales are not captured in a systematic approach. In this project, we are trying to take advantage of the bias in the samples to define family groups and individual relationships as a means to define stock structure. However, in order to design a more classical genetic monitoring program, biopsy sampling of free-ranging whales would be a valuable tool for looking at a wider range of biological questions using genetic/genomic tools.

SECTION 9: OBSERVATIONS OF KILLER WHALES IN THE BEAUFORT SEA

BACKGROUND

While killer whales have been observed intermittently within the Beaufort Sea, there are no comprehensive studies documenting where and how often sightings have occurred. This project summarized observations of killer whales from the Canadian Beaufort Sea, primarily from traditional ecological knowledge (TEK) interviews conducted in the early 1990s and mid-2000s, and from other sources including peer-reviewed journal articles, government documents, university theses, and news reports. The presence of killer whales appears to be increasing in many Arctic regions (Higdon and Ferguson 2009; Higdon *et al.* 2013; Melnikov *et al.* 2007), possibly in response to reduced ice conditions. This in turn may have a significant influence on the abundance, distribution, and behaviour of prey populations, including marine mammal species important to northern cultures. Killer whales are occasionally observed in the Beaufort Sea, although they are considered extralimital by COSEWIC (2008). Previous killer whale research in northern Canada has focused on the Eastern Arctic, and there had been no directed research focus in the Beaufort Sea region.

A total of 31 unique killer whale records were compiled, with some overlap in sources (i.e., several sources reporting the same sighting). The current compilation will provide important baseline information to assess any future changes in killer whale occurrence and distribution. Our assessment of killer whale presence within the BSS provides information needed to understand trophic interactions, model ecosystem structure and function, and inform co-management of fisheries resources.

RESULTS FROM ERI RESEARCH

- Only 18 records that could be assigned to a decade were compiled since killer whale sightings remain rare in the Canadian Beaufort Sea (range 1-5 sightings per decade since the 1940s, median 3). While rare, sightings are widely

distributed throughout the Canadian Beaufort Sea, ranging from Ulukhaktok in the east to Herschel Island in the west (Figure 19). For seven of the records, the number of whales observed was recorded, ranging from a single whale to larger groups of 15 and 20 whales. Killer whales were typically observed in summer, with reports in both July and August.

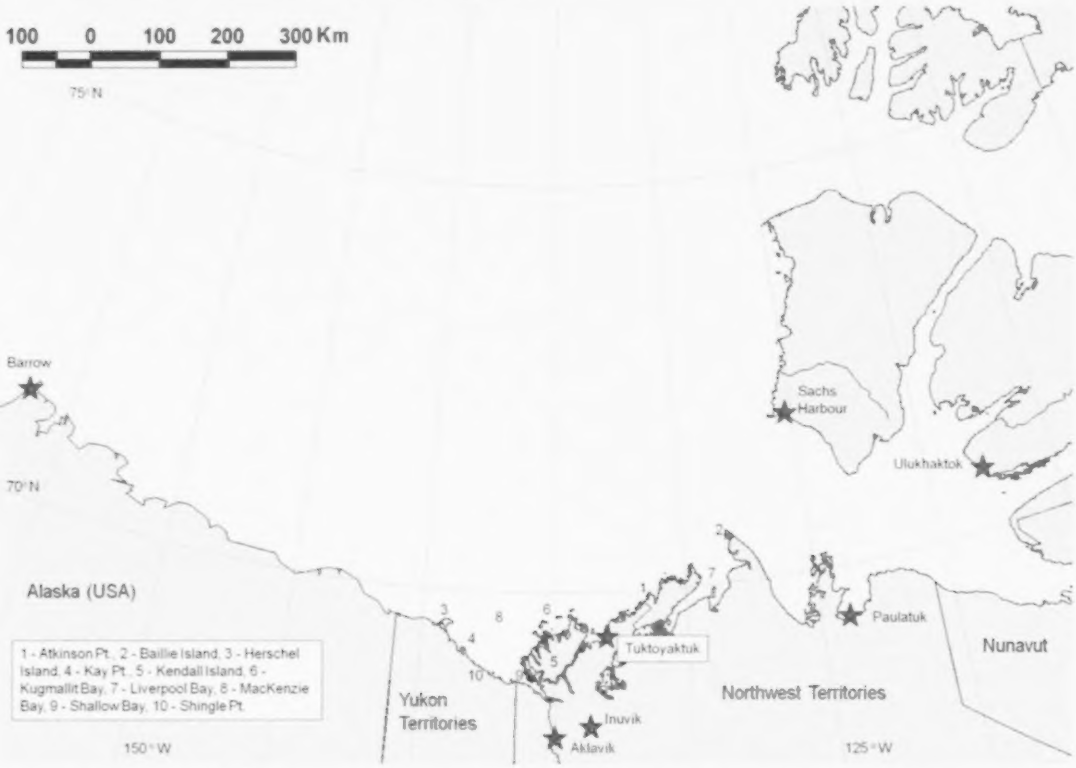


Figure 19: Map of the Canadian Beaufort Sea identifying killer whale sightings with numbers corresponding to the location of sighting as noted in legend from Higdon *et al.* 2012

- Killer whales were annually observed in the Alaskan Chukchi Sea north to Barrow, but did not appear to make regular movements eastward into the Canadian Beaufort. Killer whale observations increased in eastern Canadian waters during recent decades (Higdon et al. 2012), but this trend is apparently not occurring in the western Arctic region.

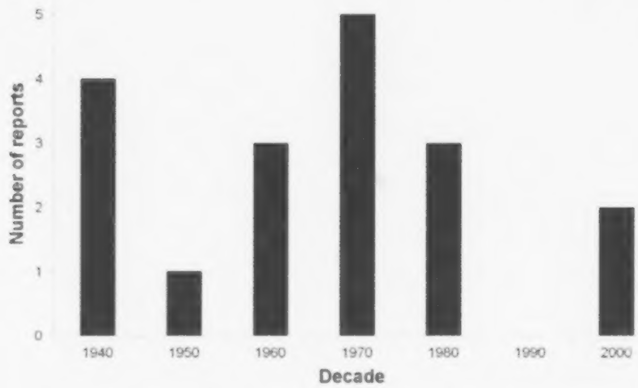


Figure 20: Number of reported killer whale observations per decade for the Canadian Beaufort Sea, for the 18 (of 31) records with temporal data

- Reported group sizes are generally representative of mammal-eating killer whales (smaller group sizes than fish-eating ecotypes), and predation on beluga whales has been reported.

GAPS IDENTIFIED

Identifying sightings in the region are important; however there is still a lack of information on the biology of killer whales in the Beaufort Sea. While some sightings include feeding behaviour, diets have not been well documented. In addition, where these whales originate from is still unknown. Future monitoring including photographs for individual photo-identification would be useful to compare with other catalogs, however as these sightings are still extremely rare, the feasibility of such a project would be low.

SECTION 10: ECOSYSTEM MODELLING OF THE BEAUFORT SEA

BACKGROUND

Past research in the Beaufort Sea has mainly been focused on individual studies, with a few large-scale sampling surveys occurring in the past. In the 1970s, Wacasey *et al.* (1977) surveyed benthos in the Mackenzie shelf area recording biomass, salinity and species composition. Pelagic surveys of phytoplankton and zooplankton have occurred under the NOGAP and *Nahidik* surveys in the 1980s and 2000s respectively, sampling species abundance (Hopky *et al.* 1994c; Hopky *et al.* 1994a; Hopky *et al.* 1994b; Walkusz *et al.* 2010). However, as these large scale assessments are few and far between, individual based research projects are required to increase our understanding of how the ecosystem functions. Species-specific research is important in building our knowledge of individual pressures on species, while large sampling exercises aid in identifying changes over time. Yet bringing together multiple species specific research programs in order to piece together ecosystem level changes is an important and arduous task.

Through the use of ecosystem models, data from a multitude of sources were combined to identify the structure of food webs. Changes to the abundance of individual components, or species, in the ecosystem were recreated using long term trends and species-specific information to identify large scale shifts in the ecosystem over time. Synthesis of data collected under various ERI programs (Sections 1 to 9) was integrated along with expert opinion in order to build an ecosystem food web model. The intention was to be able to increase our understanding of ecosystem structure and function by piecing together information on different aspects of the food web, while highlighting gaps in knowledge for future research.

Through the use of ecosystem models such as Ecopath with Ecosim (Walters *et al.* 1997; Walters *et al.* 1999), multiple impacts to the food web can be incorporated to

provide an ecosystem level assessment and evaluate impacts such as harvest and climate change over time (Christensen *et al.* 2005). Similar analysis on the Hudson Bay marine ecosystem included harvest and environmental changes under past and future simulations to identify important stressors to individual species and the ecosystem as a whole (Hoover *et al.* 2013a, 2013b). The purpose of this ERI project was to combine other ERI projects along with past research and integrate these multiple sources of information into one ecosystem model.

RESULTS FROM ERI RESEARCH

- Information on individual species (biomass, production, consumption, harvest, and diet) was incorporated into a food web model. For species where data was lacking, expert opinion from other ERI researchers was used. Species are linked together within the model via diet composition (who eats whom). The biomass of each species group is presented in Figure 21. For each group the biomass is either calculated based on previous research, or estimated by the model based on the needs of predators.

- From the food web structure, unique species can be identified based on their relative abundance and importance to the food web. In order to better understand the importance of individual components of ecosystem to the whole, a keystone index developed for the Ecopath software was used to calculate the keystoneness of each component of the food web (KS_i), where $KS_{i1} = log[\varepsilon_i(1-p_i)]$ (Power *et al.* 1996; Libralato *et al.* 2006). This equation combined the overall effect of each species group on the ecosystem (ε_i) and the contribution of each group to the food web (p_i). Species with higher values are considered more unique using this calculation (figure 21).

- Ranking of data quality and quantity available for the model is presented in the "Gaps Identified" section. Here an analysis on all available data for the model is presented and is intended to help direct future studies to complete our understanding of ecosystem structure and function.

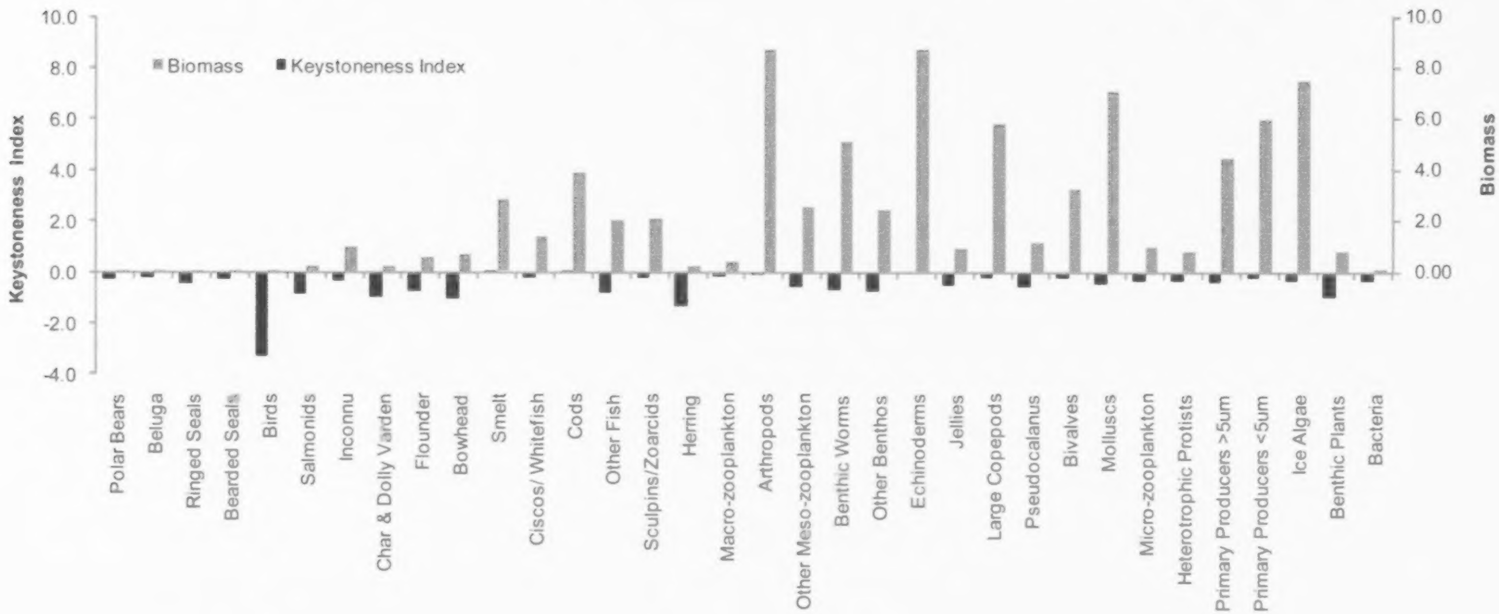


Figure 21: Biomass and Keystoneness Index as calculated for each species group of the ecosystem model. Biomass is presented in t km^{-2}. Species/ species groups are presented along the x-axis in order of trophic level ranging from polar bears (TL=4.9) to bacteria and producers (TL=1).

GAPS IDENTIFIED

Synthesis of existing literature, surveys, and other ERI research activities was a useful exercise in creating the model and identifying gaps in existing knowledge. Marine mammals are the most studied of all species groups within the area, although there are large uncertainties in population sizes. Samples of lower trophic level organisms such as benthos, zooplankton, and phytoplankton are limited in surveys. A synthesis of available information is presented in figure 22, however it should be noted these gaps are in reference to usable data from a modelling perspective. Data for many of these categories may exist, however at present they are either not available (unable to access or locate from older grey literature reports) or they are not in a usable format (raw data such as stable isotope values that need interpretation). Basic gaps identified from this large scale summary have identified the need for more fish based research in the future, as this is one of the most prominent gaps in ecosystem knowledge.

Extrapolating changes to the ecosystem, caused by different stressors, is a difficult task when the individual species responses to stressors are relatively unknown. Compiling past research into a common format points to the need for species-specific long term trend information to assess large scale changes and the causes of these changes. There is a definite need for these more detailed retrospective analyses, to build meaningful time series in order to better assess long term changes and the impacts of individual and cumulative stressors. Further research to understand the relationships between individual species and environmental impacts will be an important research focus for the future, not only to further species understanding, but also to incorporate into larger models to assess ecosystem impacts.

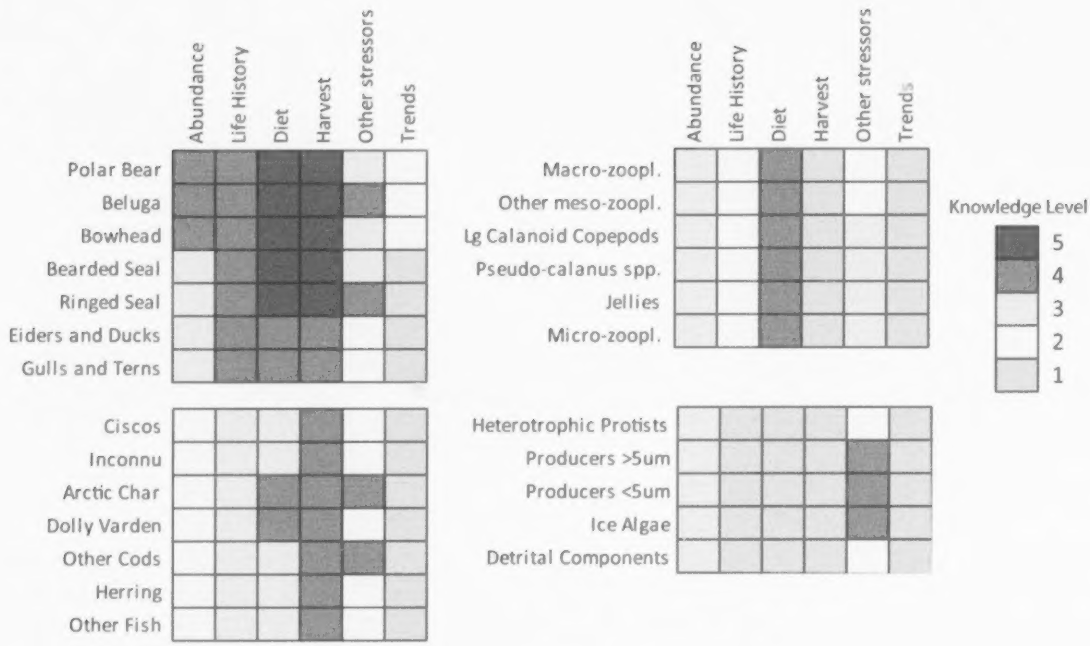


Figure 22 : Synthesis of data for species groups for the ECOPATH ecosystem model. Types of data are presented by the availability of information ranging from high (knowledge level 5) to low (knowledge level 1). Level 1 (grey) little to no data or studies available; 2 (yellow) basic information is available, no data for the region; 3 (orange) few studies available, primarily on similar species in different regions; 4 (light red) some data available for the region, but not well known; 5 (dark red) multiple studies for the region, well known. This analysis was based on the pedigree ranking in Ecopath with Ecosim (Walters *et al.* 1997), and takes into account data available for modelling purposes and does not account for raw/ inaccessible data.

CONCLUSION SECTION

CONTRIBUTION OF ERI KNOWLEDGE TO ECOSYSTEM STRUCTURE

While the BSS ERI was successful in building our understanding of ecosystem linkages, there have been many projects in the region carried out by DFO that helped to build the foundation for this research. The ERI alone did not complete our understanding of ecosystem processes and links but rather further developed past projects. The Beaufort Sea Marine Studies program (1970s) and the Northern Oil and Gas Action Program or NOGAP (1980s) were some of the first programs in the region to collect data on physical and biological processes in the Beaufort Sea. Other coastal research projects under DFO, which collected coastal fish (e.g., Phillips Bay, Tuktoyaktuk Peninsula) in the 1980s and again in the 2000s, have been integral for the development of baseline data and to help structure successive field programs. The ACES (coastal sampling) and Shingle Point monitoring (targeted Dolly Varden) programs conducted in 2000-2010 were developed based on previous coastal research projects. In 2003, Northern Coastal Marine Studies (NCMS), also known as the *Nahidik* program after the ship (CCGS *Nahidik*) focused sampling efforts on a variety of species (i.e., benthos, zooplankton, fish, oceanographic data) from approximately 5-150m depth. Following, the NCMS work, the Beaufort Regional Ecosystem Assessment (BREA) marine fishes program (2010s) is currently working to sample fish along with plankton and benthos up to depths of 1500m. Ongoing community sampling focuses on a variety of species to continue data collection. While this is not an inclusive list of research to contribute to our understanding of ecosystem structure and linkages, it highlights the decades of research preceding the ERI. Taking into consideration all the past efforts and findings, as well as those presented in the BSS ERI, a general schematic of the BSS ecosystem food web and the linkages that connect them are presented in Figure 23.

BSS ERI ACOMPLISHMENTS IN RELATION TO INITIAL TARGETS

The BSS ERI aimed to meet two sets of objectives under National and Regional themes: the first set of objectives addressed the overall themes set forward by the department in the ERI funding call, and the second set of objectives were developed by the Central and Arctic region to best fit the regional needs of the BSS ERI program. Some overlap among the objectives occurred, yet supported one another at regional and national scales.

The objectives of the ERI to be addressed by all DFO regions (as stated in the introduction) were to: 1) understand ecosystem processes, 2) understand the impacts of climate variability, and, 3) develop tools for an EBM, within each region, to focus on priorities such as fish population and community productivity, habitat and population linkages, climate variability, ecosystem assessment, and management strategies (DFO 2008). While individual projects did not meet all objectives, efforts were made to address at least one of the program objectives. We advanced our goal to enhance understanding of ecosystem processes under many ERI projects by using common approaches such as stable isotope and fatty acid analysis (e.g. sections 2: benthic data collection, 3: fish data collection, and 7: beluga data collection). ERI modeling exercises (sections 1: physical and biological processes, 4: fish stable isotope analysis, and 10: ecosystem modeling) assisted in synthesizing data from other projects to assess linkages and expand our understanding of food web structure, again supporting this objective. Only one project by C. Michel (section 1: physical and biological processes) assessed the impacts of climate variability, which demonstrated the impact of storms and river runoff on environmental variables and primary production. None of the projects developed new tools for EBM, but some applied existing techniques to data from the BSS for the first time. For example, stable isotope data analysis is a powerful tool to assess ecosystem structure, and was applied to local fish data to identify prey items for many fish in the coastal BSS (section 4). Ecosystem modeling (section 10) is also a well-developed approach to assessing the food web, but had not been applied to this geographic area before.

In parallel to the National ERI objectives, the Central and Arctic ERI addressed cumulative impacts in the BSS by: 1) assessing ecosystem linkages and processes in support of ocean health and productivity; 2) integrating research in support of modelling that addressed ecosystem questions from managers (e.g., DFO's Oceans Program, Habitat, and Fisheries and Aquaculture Management (FAM)); and, 3) building and maintaining partnerships while meeting co-management obligations to ensure future sustainability and health of the BSS. All projects within the BSS ERI worked to address the first objective of better defining ecosystem linkages either through trophic links (e.g. food web linkages) or environmental variables (e.g. habitat usage, or links with environmental/climate drivers). Most projects used either a common approach of stable isotopes or fatty acid analysis to build knowledge of food web structure or tools to model these linkages. The integration of this research to address management issues remains an ongoing goal.

Progress was made toward the second objective where novel modeling techniques were used (stable isotope and ecosystem models) to build quantitative linkages. It was demonstrated through construction of our models, that additional data is required to provide more robust models to support decision making. Furthermore, the types of analyses that can be accomplished with these approaches can be extremely useful to management decisions if these models can be validated or ground-truthed. Techniques to provide more confidence in modeling often requires large datasets or repeated sampling from the same areas to account not only for natural variability but real changes that are occurring. However current available data such as point estimates or snapshots in time, while useful to the overall goal of understanding change, are not sufficient enough at this point in time to distinguish between natural variability and changes due to stressors or cumulative impacts. This remains an ongoing goal of many projects continued within DFO Central and Arctic.

The ERI built and maintained partnerships while meeting co-management obligations to ensure future sustainability and health of the BSS. The beluga health monitoring and the ACES programs specifically developed strong linkages with communities and DFO

management sectors. These programs have provided the foundation for current and future monitoring programs in the TN MPA.

In summary, National and Regional objectives were all met in some degree by the BSS ERI program. However, a more integrated approach at the onset would have been beneficial to provide a cohesive approach and realistic expectations throughout the ERI (see Lessons Learned section below for a more detailed explanation).

SUMMARY OF POTENTIAL STRESSORS FOR THE ECOSYSTEM

In order to assess stressors within the BSS ecosystem, researchers from each project identified ecosystem level indicators, stock level indicators, and stressors related to each project and the species or trophic level they study (Table 6). In addition, researchers also attempted to identify potential thresholds or trigger-points that could be used for monitoring in the future (Table 6). From this exercise, a number of common threats to the ecosystem were also identified. However, there are still a number of gaps in knowledge on how some of these organisms will respond to the threats and stressors and in determining the appropriate thresholds for monitoring. Regardless of these gaps, highlighting our current knowledge is an important step to the ERI goal of assessing cumulative impacts in an ecosystem-based approached.

Collaboratively, seven major stressors (or activities) to the BSS ecosystem (climate change, commercial fishing, contaminants and diseases, hydrocarbon development, subsistence harvest, recreation and tourism, and shipping) were identified, also by BSS ERI researchers, and ranked by individual species or trophic level (Table 7). Here, a general rank of high to low is applied to each species or trophic level assessed under the ERI program. From this exercise, commercial fish was identified as a potential threat, although there is still a lack of data on the issue (Table 7). Climate change is also highlighted as an important future stressor to the region. Since there is little recreation and tourism currently in the region, these are identified as a low future threat.

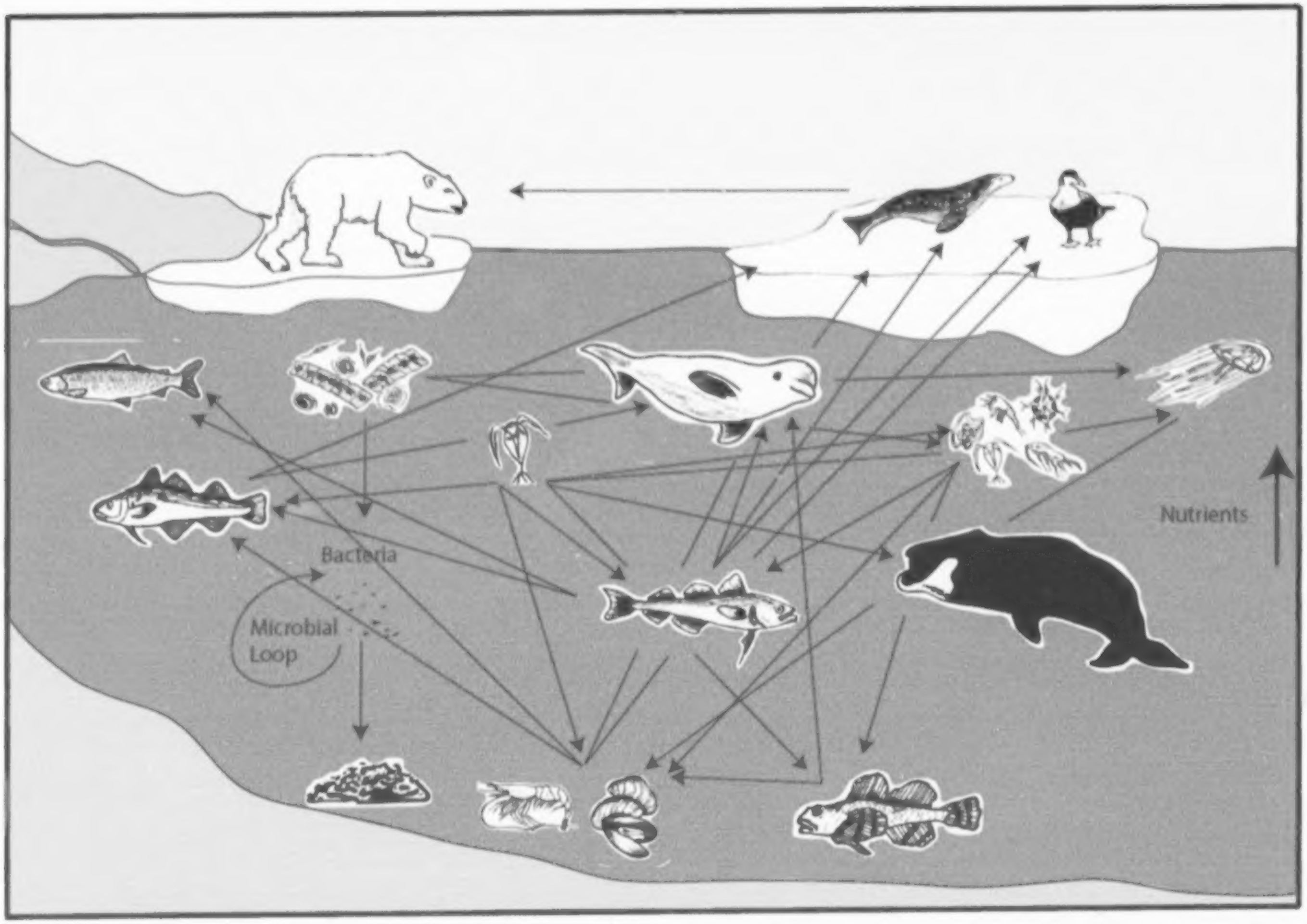


Figure 23: Ecosystem diagram of the Beaufort Sea Shelf highlighting key ecosystem components and linkages identified from the ERI and past research programs. Linkages between species highlight key interactions in the ecosystem and are not inclusive.

Table 6: Summary of potential indicators and stressors as they relate to individual species or trophic levels. All potential indicators and stressors are proposed by lead researchers as they pertain to individual ERI projects.

Project Name	**Physical, chemical, and biological conditions that define ecosystem architecture**	**Structure of lower trophic levels in the nearshore regions of the Beaufort Sea**	**Arctic Coastal Ecosystem Studies**
Trophic Level /Species of Study	Primary Producers	Benthos	Fish and Benthos
Key Threats or Stressors	Climate Change, hydrocarbon development (spills), shipping, changing ice conditions.	Climate change, increased marine traffic, changes in permafrost, sediment load, nutrients, primary production, invasive species.	Climate change (changes in food chain), contamination (from shipping, oil/gas extraction), noise (shipping, oil/gas activity), habitat disturbance (oil/gas activity).
Potential Ecosystem Level indicators	Numerous indicators are proposed, but more research is needed to identify specific ones. Examples: protist community composition, oceanographic variables, type/availability of sea ice habitat.	Temperature change, ice cover (number of ice free days), sediment load, permafrost degradation.	Quantity and quality of food available, contaminants in the food web, water quality.
Potential Trophic Level indicators	Presence/absence of dominant species.	Community composition metrics.	Changes in SI or FA in relation to physical environmental changes, concentrations of biomagnifying contaminants (e.g., Hg).
Potential Stressor Response indicator	Not yet determined.	Community composition metrics.	Changes in distribution, changes in abundance, health indices (not yet developed).
Trigger Levels or Thresholds of Concern	Not yet determined.	Qualitative: Change in predators or predators' diets, changes in reproductive behaviour due to match-mismatch (related to temperature and food availability).	Unknown. Currently identifying inter- and intra-species variability to provide natural variability so it can be compared to changes in the future.

Table 6 continued on next page

Table 6 Continued

Project Name	**Understanding fish diets through stable isotope analysis at Philips Bay**	**Identification of emerging infectious disease threats to marine mammals in the Beaufort Sea**	**Distribution, movements, and behaviour of bowhead whales, beluga whales, and ringed seals**
Trophic Level /Species of Study	Fish	Marine Mammals	Marine mammals (beluga, bowhead, ringed seals)
Key Threats or Stressors	Water temperature, freshwater discharge, increases in contaminant concentration (water or sediment), harvest.	Changes in ice structure, habitat, prey changes (from climate change), invasive species.	Climate change, harvest, prey shifts, noise (industrial activity).
Potential Ecosystem Level Indicators	Number of fish species present, length of food chain, food web metrics.	Temperature change, ice cover (number of ice free days).	Changes in ice cover, changes in prey species.
Potential Trophic Level indicators	Species-specific condition, C:N, and relative proportion of marine- vs. freshwater-derived prey, concentrations of biomagnifying contaminants (e.g., Hg).	Incidence of sick and dead stranded beluga and ringed seals.	Harvest levels, body condition (reproductive success).
Potential Stressor Response Indicator	Contaminants, food web structure, shifts in marine vs. freshwater habitat use, change in condition (C:N ratios).	Changes in pathogenicity and host range of marine mammals (genomics), number of stranded/ dead animals. Hunter observations of concern. Introduction of "new" diseases	Displacement due to industrial noise, changes in relative abundance and distribution.
Trigger Levels or Thresholds of Concern	Contaminants: Increases above CCME guidelines. Structure: Change in total length of food chain by 1 or more trophic levels. Marine vs freshwater habitat use: Documented change in 3 + consecutive years of 10% or more. Change in condition or C:N ratios 10% change (decrease).	Needs more information.	Noise thresholds will differ by species, substrate, season, and type of activity.

Table 6 continued on next page

Table 6 continued

Project Name	Beluga health	Genetic monitoring and conservation of beluga whales	Beaufort Sea killer whale observations	Ecosystem modelling of the Beaufort Sea Shelf
Trophic Level /Species of Study	Marine Mammals (beluga)	Marine Mammals (beluga)	Marine Mammals (killer whales)	All: whole ecosystem
Key Threats or Stressors	Climate change, changes in prey quality/quantity, changes in contaminant and disease exposure, changes in habitat quality/availability.	Not Identified by this project.	Climate change (entrapments).	Climate change, harvest, changes in food web structure.
Potential Ecosystem Level Indicators	Changes in diet, food web structure.	Changes in prey or predator abundance/ distribution. Changes in habitat use.	Changes in abundance/ distribution.	Changes in food web (length of food web, changes in energy flow).
Potential Trophic Level Indicators	SI, FA, and other potential diet tracers (Hg).	Changes in the size of groups, timing of movements.	Group composition and diet.	Keystone species, changes in biomass.
Potential Stressor Response Indicator	Changes in hormone levels and stressor gene expression (Cyp1A), lipid quality and quantity.	Social structure, habitat use, beluga abundance and distribution.	Needs more data.	See ecosystem level indicators (this table).
Trigger Levels or Thresholds of Concern	Thresholds for contaminants have been determined using captive studies (Ross *et al.* 1995), standings (Hall *et al.* 2006) and recent endocrine markers (Mos *et al.* 2007)	Not enough data yet to be able to make any predictions for this.	Need more information.	Changes in model group biomass (>20% of historical values).

SUMMARY OF GAPS IDENTIFIED IN THE ERI PROGRAM

While there are still many gaps in our understanding of the BSS ecosystem, the ERI has allowed the opportunity to provide baseline information for many species in the ecosystem. Stable isotope data has been collected for numerous zooplankton, benthic, fish and mammal species in order to provide information on linkages within the food web. Although this may be considered preliminary, it is essential information needed for managing species. The importance of prey items to marine mammals will assist in management of marine mammal stocks and will be crucial to understanding changes to come under different future climate. Environmental changes associated with climate change will impact species across all levels. The ability to account for all species within the ecosystem and their functioning roles is a first step to helping the region understand how these roles in the ecosystem will change with environmental changes. Future research will help to fill in existing gaps for species whose roles are not well identified within the ecosystem, and will help to identify important stressors to the ecosystem as a whole in addition to single species. For example, our understanding of fish is still a key gap in the ecosystem. While samples collected as part of the ACES program and food web models have been developed, these have focused on coastal or shelf samples. Our understanding of fish biology and distribution beyond the shelf is poor.

Perhaps the largest gap identified is the lack of long-term datasets in the Beaufort region. While this is in part due to the nature of Arctic research (e.g., expensive and logistically difficult to access and sample), trend data is essential in order to further assess the impact of stressors. We must first understand natural variability within populations and impacts of individual stressors before we can build to assess cumulative stressors on the entire ecosystem. Long-term data collected through monitoring programs is essential to assessing future impacts. However, the nature of DFO funding cycles (3-5 years depending on programs) makes establishing this type of research difficult. Continued efforts to piece together long term datasets via various funding programs will be ongoing.

LESSONS LEARNED FROM THE ERI PROGRAM

The process of organizing a multi-year ecosystem-based research program was a new initiative led internally by DFO. Many lessons were learned along the way, and will provide guidance in future work. The goal of the BSS ERI (as previously stated) was to begin to support DFO's ability to address the cumulative impacts of multiple stressors in an integrated, ecosystem-based approach. However, it is well documented that the framework or process by which you address cumulative impacts is a national challenge for the Department. The ERI would have benefited from having a better understanding of how each programs output would feed into the larger assessment process at the end. In addition, the evolution of project outputs as work was conducted and the evolution of Departmental assessment frameworks over the span of the ERI limited the ability of researchers and project organizers from having a clear approach to the goals of the program. Throughout the span of the ERI, the intent remained general and highlighted the ecosystem-based approach, but could have been achieved with a myriad of approaches. While this goal is a process, many efforts have been successful in developing a greater understanding of ecosystem linkages and impacts of stressors such as changes in climate and increased contaminants. The goals of the ERI remain a priority for research in the BSS.

The early phases of the ERI BSS program supported many valuable individual research projects that were not established in a cohesive manner. Although many of the projects did feed directly into client needs/interests, the fact that components occurred independently did not help the program proceed as a whole in an integrated fashion. However, the inclusion of the ecosystem model and the concept of introducing stressors to the model did help to refocus the projects to a common goal by insisting on standardized data for all the ecosystem components. Overall, this ERI project would have benefited from a more specific mandate at the onset in order develop a more inclusive and complete program framework that may have initiated integration earlier on within the ERI.

FUTURE RESEARCH IN THE BEAUFORT SEA SHELF

Many of the research projects currently within DFO are working to expand on the ERI research and continue to expand our understanding of ecosystem dynamics. Assessing ecosystem stressors and developing approaches to determine the effects of cumulative impacts of these stressors is an ongoing goal for research at DFO. ERI projects have contributed to this knowledge, but a more formal assessment process of stressors is still needed. Researchers contributing to the BSS ERI have provided information on common stressors (Table 7) as a step towards a more integrated assessment. This information provided is based on the expert opinions of researchers, as a first step towards a high level assessment of stressors to assist decision making processes.

While only some of the ERI programs are specifically aimed at ecosystem-based research, many are continuing individual projects from the BSS ERI within an ecosystem context, to build on what was accomplished under the ERI. The Strategic Program for Ecosystem-Based Research and Advice (SPERA)[2] was initiated in 2012 to support research projects and scientific tool development aimed at managing ecosystems at the national level. While some regional-based projects were funded under this program, they served as pilot programs in a national agenda for ecosystem-based research. A key component of SPERA is the development of scientific tools to support ecosystem management at the national scale.

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[2] http://www.dfo-mpo.gc.ca/science/ecosystem-eng.htm

Table 7: Summary of potential stressors to the Beaufort Sea Shelf and risk level to species/ trophic levels. Stressors are ranked as High (H), Medium (M), or Low (L) risk, No Data (ND), or Not Applicable (N/A).

Species/ Trophic Level	Producers	Benthos	Coastal Fish	Ringed seals	Beluga	Bowhead	Killer whales	All Trophic Levels
Climate Change	H	H	H	H	M	M	ND	H
Commercial Fishing	ND	ND	ND	ND	ND	ND	ND	M
Contaminants and Diseases	ND	ND	H	M	H	L	ND	ND
Hydrocarbon Development and associated activities	M	H	M	L	M	M	ND	ND
Subsistence Harvesting	N/A	N/A	L	L	L	L	N/A	M
Recreation and tourism	L	L	L	L	L	L	L	L
Shipping (Noise and Disturbances)	M	M	M	L	H	H	ND	L

Another national research program is the Aquatic Climate Change Adaptation Services Program (ACCASP), which started in 2011. This program was designed to improve the understanding of climate change and to help Canadians prepare for climate-related impacts[3]. This program is also focused on developing applied science based tools to help meet strategic outcomes in addition to producing new knowledge regarding climate change. Under this program, future simulations of the ecosystem model are being developed (C. Hoover, L. Loseto) in partnership with other regions (Pacific and Maritimes) to assess the effectiveness of using ecosystem models for future climate change simulations. Under this project, multiple stressors such as future climate change and local harvest levels are incorporated at different levels to run ecosystem model simulations for the Beaufort Sea model and assess the impacts to the food web.

Finally, the Beaufort Regional Environmental Assessment (BREA)[4] is a regional environmental and socio-economic initiative started in 2011 to respond to new investments in oil and gas in the Beaufort Sea. This regional assessment involves many stakeholders and research projects from government, academia and industry. Under the BSS ERI and other previous research programs, data has been collected on fish for the coastal and shelf areas. Further sampling of fish in the offshore regions is being completed under BREA research (J. Reist) to assess the abundance, distribution, and composition of fish communities in deeper waters. This is the first time fish have been sampled in deeper (>200m) waters in the region by DFO, and will help to build our knowledge of ecosystem dynamics off the shelf region.

CONCLUSION

The contribution of ERI funding allowed for the integration of individual projects and the construction of an ecosystem model, with further development of many projects continuing under recent initiatives. While research aimed at reaching the goals set under the BSS ERI is ongoing, many strides have been made to increase our

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[3] http://www.dfo-mpo.gc.ca/science/oceanography-oceanographie/accasp/index-eng.html
[4] http://www.aadnc-aandc.gc.ca/eng/1310583424493/1310583559732

understanding of ecosystem structure and function. Although the overarching goal of assessing cumulative impacts on the ecosystem was not fully accomplished during the ERI, many continuing research projects established under the ERI are fulfilling this goal. The lessons learned about the establishment of a multi-year, multi-researcher, ecosystem-based project will help to direct future programs at DFO.

REFERENCES

Arrigo, K. Perovish, D., Pickart, R., Brown, Z., van Dijken, G., Lowry, K., Mills, M., Palmer, M., Balch, W., Bahr, F., Bates, N., Benitez-Nelson, C., Bowler, B., Brownlee, E., Ehn, J., Frey, K.., Garley, R., Laney, S., Lubelczyk, L., Mathis, J., Matsuoka, A., Mitchell, B., Moore, G., Ortega-Retuerta, E., Pal, S., Polashenski, C., Reynolds, R., Shieber, B., Sosik, H., Stephens, M. and Swift, J. 2012. Massive phytoplankton blooms under Arctic sea ice. Science **336**: 1408.

Brouwer, A., Reijnders, P. and Koeman, J. 1989. Polychlorinated biphenyl (PCB)-contaminanted fish induces vitamin A and thyroid hormone deficiency in the common seal (*Phoca vitulina*). Aquatic Toxicology **15**: 99-106.

Christensen, V., Walters, C. and Pauly, D. 2005. Ecopath with Ecosim: A user's guide. Vancouver, BC, Fisheries Centre, University of British Columbia: 1-154.

Cobb, D. 2011. Identification of Ecologically and Biologically Significant Areas (EBSAs) in the Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/070: vi+38p.

Cobb, D., Fast, H., Papst, M., Rosenberg, D., Rutherford, R. and Sareault, J. (Eds). 2008. Beaufort Sea Large Ocean Management Area ecosystem overview and assessment report. Can. Tech. Rep. Fish. Aquat. Sci. 2780: ii-ix + 188 p.

COSEWIC 2008. COSEWIC assessment and update status report on the Killer Whale *Orcinus orca*, Southern Resident population, Northern Resident population, West Coast Transient population, Offshore population and Northwest Atlantic / Eastern Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. viii + 65 pp.

DFO 2004. Identification of Ecologically and Biologically Significant Area. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2004/006.

DFO 2008. Fisheries and Oceans Canada: Five-Year Research Plan 2008-2013. Fisheries and Oceans Canada, Ottawa: 23p.

DFO 2011. Identification of Ecologically and Biologically Significant Areas (EBSA) in the Canadian Arctic. Science Advisory Report 2011/055. DFO Canadian Science Advisory Secretariat: 40p.

DFO 2013. National synthesis of the Ecosystem Research Initiatives. Science Advisory Report 2013/026. DFO Canadian Science Advisory Secretariat: 13p.

Fraker, M., Gordon, C., McDonald, J., Ford, J. and Cambers, G. 1979. White whale (*Delphinapterus leucas*) distriubtion and abundance and the relationship to physical and chemical characteristics of the Mackenzie Estuary. Fisheries and Marine Service Technical Report 863. Winnipeg, Department of Fisheries and Environment: 56p.

Frouin, H., Loseto, L., Stern, G., Haulena, M. and Ross, P. 2012. Mercury toxicity in beluga whale lymphocytes: Limited effects of selenium protection. Aquatic Toxicology 109: 185-193.

Hall, A., Mcconnell, B., Rowles, T., Aguilar, A., Borrell, A., Schwacke, L., Reijnders, P. and Wells, R., 2006. Individual-based model framework to assess population consequences of polychlorinated biphenyl exposure in bottlenose dolphins. Environmental Health Perspectives **114**: 60-64.

Harwood, L. and Kingsley, M. 2013. Trends in the Offshore Distribution and Relative Abundance of Beaufort Sea Belugas, 1982 – 85 vs 2007 – 09. Arctic **66(3)**: 247-256.

Higdon, J. and Ferguson, S. 2009. Loss of Arctic sea ice causing punctuated change in sightings of killer whales (*Orcinus orca*) over the past century. Ecological Applications **19**: 1365–1375.

Higdon, J., Byers, T., Brown, L. and Ferguson, S. 2013. Observations of killer whales (*Orcinus orca*) in the Canadian Beaufort Sea. Polar Record **49(250)**: 307–314.

Higdon, J., Hauser, D. and Ferguson, S. 2012. Killer whales (*Orcinus orca*) in the Canadian Arctic: distribution, prey items, group sizes, and seasonality. Marine Mammal Science **28(2)**: E93–E109.

Hobson, K., Fisk, A., Karnovsky, N., Holst, M., Gagnon, J.-M. and Fortier, M. 2002. A stable isotope (C, N) model for the North Water food web implications for evaluating trophodynamics and the flow of energy and contaminants." Deep-Sea Research II **49**: 5131-5150.

Hopky, G., Lawrence, M. and Chiperzak, D. 1994a. NOGAP B2: Zooplankton Data from the Canadian Beaufort Sea shelf, 1984 and 1985. Can. Dat. Rep. Fish. Aquat. Sci. 922: v + 164 p.

Hopky, G., Lawrence, M. and Chiperzak, D. 1994b. NOGAP B2: Zooplankton Data from the Canadian Beaufort Sea shelf, 1986. Can. Dat. Rep. Fish. Aquat. Sci. 923: iv + 225 p.

Hopky, G., Lawrence, M. and Chiperzak, D. 1994c. NOGAP B2 : Zooplankton Data from the Canadian Beaufort Sea shelf, 1987 and 1988. Can. Dat. Rep. Fish. Aquat. Sci. 912: v + 219 p.

Hoover, C., Pitcher, T. and Christensen, V. 2013a. Effects of hunting, fishing and climate change on the Hudson Bay marine ecosystem: I. Re-creating past changes 1970–2009. Ecological Modelling **264** (Special Issue: Global Climate Change and Marine Ecosystems): 130-142.

Hoover, C., Pitcher, T. and Christensen, V. 2013b. Effects of hunting, fishing and climate change on the Hudson Bay marine ecosystem: II. Ecosystem model future projections. Ecological Modelling **264** (Special Issue: Global Climate Change and Marine Ecosystems): 143-156.

Jensen, T., Van de Bildt, M., Dietz, H., Anderson, T., Hammer, A., Kuiken, T. and Osterhaus, A. 2002. Another phocine distemper outbreak in Europe. Science **297**: 209.

Juul-Pedersen, T., Michel, C. and Gosselin, M. 2008. Influence of the Mackenzie River plume on the sinking export of particulate material on the shelf. Journal of Marine Systems **74**: 810-824.

Layman, C., Arrington, D., Montana, C. and Post, D. 2007. Can stable isotope ratios provide for community-wide measures of trophic structure? Ecology **88**:42-48.

Libralato, S., Christensen, V. and Pauly, D. 2006. A method for identifying keystone species. Ecological Modelling **195**: 153-171.

Loseto, L., Stern, G. and Ferguson, S. (2008). Size and biomagnification: How habitat selection explains beluga mercury levels. Environmental Science & Technology, **42(11)**: 3982-3988.

Loseto, L., Stern, G., Connelly, T., Deibel, D., Prokopowicz, A., Gemmill, B., Fortier, L. and Ferguson, S. 2009. Summer diet of beluga whales inferred by fatty acid analysis of the eastern Beaufort Sea food web. Journal of Experimental Marine Biology and Ecology, **374**:12-18.

Mos, L., Tabuchi, M., Dangerfield, N., Jeffries, S., Koop, B. and Ross, P. 2007. Contaminant-associated disruption of vitamin A and its receptor (RAR) in free-ranging harbour seals (*Phoca vitulina*). Aquatic Toxicology **81**: 319–328.

Manson, G. and Solomon, S. 2007. Past and future forcing of Beaufort Sea coastal change. Atmosphere-Ocean **45**:107-122.

Melnikov, V., IZagrebin, I., Zelensky, G. and Ainana, L. 2007. Killer whales (*Orcinus orca*) in waters adjacent to the Chukotka Peninsula, Russia. Journal of Cetacean Research and Management **9**: 53–63.

Muir, D., Ford, C., Stewart, R., Smith, T., Addison, R., Zinck, M. and Beland, P. 1990. Organochlorine contaminants in belugas, *Delphinapterus leucas*, from Canadian waters. Canadian Bulletin of Fisheries and Aquatic Sciences **224**: 165-190.

Mundy, C., Gosselin, M., Ehn, J., Gratton, Y., Rossnagel, A., Barber, D., Martin, J., Tremblay, J-É., Palmer, M., Arrigo, K., Darnis, G., Fortier, L., Else, B. and Papakyriakou, T. 2009. Contribution of under-ice primary production to an ice-edge upwelling phytoplankton bloom in the Canadian Beaufort Sea. Geophysical Research Letters. **36**:L17601.

Niemi, A., Johnson, J., Majewski, A., Mellling, H., Reist, J. and Williams, W. 2012. State of the ocean report for the Beaufort Sea Large Ocean Management area. Can. Manuscr. Rep. Fish. Aquat. Sci. 2977: vi + 51 p.

Paulic, J., Papst, M. and Cobb, D. 2009. Proceedings for the identification of ecologically and biologically significant areas in the Beaufort Sea Large Ocean Management Area. Can. Manuscr. Rep. Fish. Aquat. Sci. 2865 : ii + 46 p.

Power, M., Tilman, D., Estes, J., Menge, B., Bond, W., Mills, S., Daily, G., Castilla, J., Lubchenco, J. and Paine, R. 1996. Challenges in the quest for keystones. Bioscience **46(8)**: 609-620.

Ross, P., De Swart, R., Reijnders, P., Van Loveren, H., Vos, J. and Osterhaus, A. 1995. Contaminant-related suppression of delayed-type hypersensitivity and antibody responses in harbor seals fed herring from the Baltic Sea. Environmental Health Perspectives **103**: 162-167.

Ross, P., De Swart, R., Timmerman, H., Reijnders, P., Vos, J., Van Loveren, H. and Osterhaus, A. 1996. Suppression of natural killer cell activity in harbour seals (*Phoca vitulina*) fed Baltic Sea herring. Aquatic Toxicology **34**: 71-84.

Safe, S. 1994. Polychlorinated biphenyls (PCBs): environmental impact, biochemical and toxic responses, and implications for risk assessment. Critical Reviews in Toxicology **24**: 87-149.

Saliki, J., Cooper, E. and Gustavson, J. 2002. Emerging morbillivirus infections of marine mammals. Annals of the New York Academy of Sciences. **969**: 51-59.

Simon, A., Chambellant, M., Ward, B., Simard, M., Proulx, J., Levesque, B., Bigras-Poulin, M., Rousseau, A. and Ogden, N. 2011. Spatio-temporal variations and age effect on *Toxoplasma gondii* seroprevalence in seals from the Canadian Arctic. Parasitology **138(11)**: 1362-8.

Stroeve, J., Serreze, M., Holland, M., Kay, J., Malanik, J. and Barrett, A. 2011. The Arctic's rapidly shrinking sea ice cover: A research synthesis. Climatic Change **110(3-4)**: 1005-1027.

Tabuchi, M., Veldhoen, N., Dangerfield, N., Jeffries, S., Helbing, C. and Ross, P. 2006. PCB-related alteration of thyroid hormones and thyroid hormone receptor gene expression in free-ranging harbor seals (*Phoca vitulina*). Environmental Health Perspectives **114(7)**: 1024-1030.

Tang, S., Larouche, P., Niemi, A. and Michel, C. 2013. Regional algorithms for remote-sensing estimates of total suspended matter in the Beaufort Sea. International Journal of Remote Sensing **34(19)**: 6562-6576.

Tremblay, J.-É., Bélanger, S., Barber, D., Asplin, M., Martin, J., Darnis, G., Fortier, L., Gratton, Y., Link, H., Archambault, P., Sallon, A., Michel, C., Williams, W., Phillippe, B. and Gosselin, M. 2011. Climate forcing multiplies biological productivity in the coastal Arctic. Geophysical Research Letters **38**: L18604.

Usher, P. 2002. Inuvialuit Use of the Beaufort Sea and its Resources, 1960-2000. Arctic **55(Supp 1)**: 18-28.

Wacasey, J., Atkinson, E., Derick, L. and Weinstein, A. 1977. Zoobenthos data from the southern Beaufort Sea, 1971-1975. Fisheries and Marine Service Data Report 41: iv+187p.

Walkusz, W., Paulic, J., Kwasniewski, S., Williams, W., Wong, S. and Papst, M. 2010. Distribution, diversity and biomass of summer zooplankton from the coastal Canadian Beaufort Sea. Polar Biology **33(3)**: 321-335.

Walkusz, W. and Williams, W. (Eds.) 2013. Northern Coastal Marine Studies – the Nahidik Program – Environmental Research of the Coastal Canadian Beaufort Sea. Journal of Marine Systems (Special Issue) **127**: 1-100.

Walters, C., Christensen, V. and Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophicmass-balance assessments. Reviews in Fish Biology and Fisheries **7(2)**: 139-172.

Walters, C., Pauly, D. and Christensen, V. 1999. Ecospace: Prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. Ecosystems **2(6)**: 539-554.

Williams, W. and Carmack, E. 2008. Combined effect of wind-forcing and isobath divergence on upwelling at Cape Bathurst, Beaufort Sea. Journal of Marine Research **66(5)**: 645-663.

Wieckowski, K., Marmorek, D., Christensen, V. and Preikshot, D. 2010. Beaufort ERI: Integrated ecosystem modeling synthesis report. Prepared for Fisheries and Oceans Canada. Workshop proceedings prepared by ESSA Technologies Ltd., Vancouver, BC for the Arctic Aquatic Research Division, Fisheries and Oceans Canada, Winnipeg, Manitoba. 30 pp.

APPENDIX A: PUBLICATIONS ARISING FROM ERI FUNDED WORK

Addison, R., Muir, D., Ikonomou, M., Harwood, L. and Smith, T. 2009. Hexachlorocyclohexanes (HCH) in ringed seal (*Phoca hispida*) from Ulukhaktok (Holman), NT: trends from 1978 to 2006. Science of the Total Environment **407**: 5139-5146.

Addison, R., Muir, D., Ikonomou, M., Harwood, L. Smith, T. and Alikamik, J. 2013. Temporal trends in "legacy" organochlorine contaminants in blubber of ringed seals (*Phoca hispida*) from Ulukhaktok, NT, Canada between 1972 and 2010. Science of the Total Environment. **466-467**: 564-76.

Bell, R. and Harwood, L. 2012. Harvest-based monitoring in the Inuvialuit Settlement Region: Steps for Success. Arctic **64(4)**: 421-432.

Desforges, J-P., Ross, P. and Loseto, L. 2012. Transplacental transfer of polychlorinated biphenyls and polybrominated diphenyl ethers in Arctic beluga whales (*Delphinapterus leucas*). Environmental Toxicology and Chemistry. **31**: 296-300.

Desforges, J-P., Ross, P. and Loseto, L. 2013. Metabolic transformation shapes PCB and PBDE patterns in western Arctic beluga whales (*Delphinapterus leucas*). Submitted to Environmental Toxicology and Chemistry **32(5)**: 1132-1142.

Ferguson, S., Asselin, N., Loseto, L. and Higdon, J. 2012. Marine mammals. In: Barber, D., Tjaden, T., Leitch, D., Barber, L. and Chan, W (Eds). On the edge: from knowledge to action during the fourth International Polar Year Circumpolar Flaw Lead system study (2007-2008). Prolific Printing, Winnipeg, Canada. pp 95-108.

Frouin, H., Loseto, L., Stern, G., Haulena, M. and Ross, P. 2012. Mercury toxicity in beluga whale lymphocytes: limited effects of selenium protection. Aquatic Toxicology, **109**: 185-193.

Gaden, A., Ferguson, S., Harwood, L., Melling, H. and Stern, G. 2009. Mercury trends in ringed seals (*Phoca hispida*) from the western Canadian Arctic since 1973: associations with sea ice duration. Environmental Science & Technology **43(10)**: 3646–3651.

Gaden, A., Ferguson, S., Harwood, L., Melling, H., Alikamik, J. and Stern, G. 2012. Western Canadian Arctic ringed seal organic contaminant trends in relation to sea ice break-up. Environmental Science & Technology **46(8)**: 4427–4433.

Harwood, L. and Joynt, A. 2009. Factors influencing the effectiveness of marine mammal observers on seismic vessels, with examples from the Canadian Beaufort Sea. DFO Canadian Science Advisory Secretariat Research Document 2009/048: iv + 9 p.

Harwood, L. and Kingsley, M. (In Review) Relative abundance and distribution of beluga whales in the offshore Beaufort Sea during late August: 1982-1985 and 2007-2009. Submitted to Arctic.

Harwood, L. and Kingsley, M. 2013. Trends in offshore distribution and relative abundance of Beaufort Sea beluga, 1982-1985 vs 2007-2009. Arctic **66(3)**: 247-256.

Harwood, L. and Kingsley, M. (In Review). Hunter-based monitoring of the Mackenzie Delta and Paulatuk, NT, Canada subsistence harvest of belugas: harvesting trends, growth and reproduction, 1980 to 2009. Arctic.

Harwood, L., Joynt, A., Kennedy, D., Pitt, R. and Moore, S. 2009. Spatial restrictions and temporal planning as measures to mitigate potential effects of seismic noise on cetaceans: a working example from the Canadian Beaufort Sea, 2007-2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/040: iv + 14p.

Harwood, L., Auld, J., Joynt, A. and Moore, S. 2010. Distribution of bowhead whales in the SE Beaufort Sea during late summer, 2007-2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/111: v + 22 p.

Harwood, L., Joynt, A., Kennedy, D., Pitt, R. and Moore, S. 2010. Spatial restrictions and temporal planning as measures to mitigate potential effects of seismic noise on cetaceans: a working example from the Canadian Beaufort Sea, 2007-2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/040: iv + 14 p.

Harwood, L., Smith, T. and Auld, J. 2012. Fall migration of ringed seals (*Phoca hispida*) through the Beaufort and Chukchi seas, 2001-2002. Arctic **65(1)**: 35-44.

Harwood, L., Smith, T., Melling, H., Alikamik, J. and Kingsley, M. 2012. Ringed seals and sea ice in Canada's Western Arctic: harvest-based monitoring 1992-2011. Arctic **65(4)**: 377-390.

Harwood, L., Iacozza, J. and Loseto, L. (In Review). Beluga habitat use in four bays of the Mackenzie River estuary, July 1977 to 1992. Arctic.

Harwood, L., Smith, T., Auld, J. and Melling, H. (In Review). Movements and diving of free-ranging ringed seals, *Phoca hispida*, in the western Canadian Arctic, 1999-2002 and 2010-2011. Arctic.

Higdon, J., Hauser, D. and Ferguson, S. 2012. Killer whales (*Orcinus orca*) in the Canadian Arctic: distribution, prey items, group sizes, and seasonality. Marine Mammal Science **28(2)**: E93–E109.

Higdon, J., Byers, T., Brown, L. and Ferguson, S. 2013. Observations of killer whales (*Orcinus orca*) in the Canadian Beaufort Sea. Polar Record **49(250)**: 307–314.

Hoover, C. (in prep). Assessing the effects of cumulative impacts on the Beaufort Sea coastal and marine food webs.

Juul-Pedersen, T., Michel, C. and Gosselin, M. 2008. Influence of the Mackenzie River plume on the sinking export of particulate material on the shelf. Journal of Marine Systems **74**: 810-824.

Loseto, L., Richard, P., Stern, G., Orr, J. and Ferguson, S. 2006. Segregation of Beaufort Sea Beluga Whales during the Open-Water Season. Canadian Journal of Zoology **1751**: 1743–1751. doi:10.1139/Z06-160.

Loseto, L., Stern, G., Connelly, T., Deibel, D., Prokopowicz, A., Gemmill, B., Fortier, L. and Ferguson, S. 2009. Summer diet of beluga whales inferred by fatty acid analysis of the eastern Beaufort Sea food web. Journal of Experimental Marine Biology and Ecology, **374**:12-18.

Loseto, L., Wazny, T., Cleator, H., Ayles, B., Cobb, D., Harwood, L., Michel, C., Nielsen, O., Paulic, J., Postma, L., Ramlal, P., Richard, P., Ross, P., Solomon, S., Walkusz, W., Weilgart, L. and Williams, B. 2010. Information in support of indicator selection for monitoring the Tarium Niryutait Marine Protected Area (TN MPA). DFO Can. Sci. Advis. Sec. Res, Doc. 2010/nnn. iv + 42 p.

Loseto, L., Noel, M. and Ross, P. (In Review) Feeding ecology and contaminant exposure: What Risks does a receding ice edge bring to the Beaufort Sea Beluga Whales? Submitted to Environmental Toxicology and Chemistry.

Macdonald, R. and Loseto, L. 2010. Are Arctic Ocean Ecosystems Exceptionally Vulnerable to Global Emissions of Mercury? A call for emphasized research on methylation and the consequences of climate change. Environmental Chemistry **7**: 133-138.

Mudge, T., Milutinovic, N., Bartlett, J. and Birch, R. 2011. ADCP, CTD and CLW measurements in the Beaufort Sea- July 2010. Report for DFO, Arctic Aquatic Research Division, Winnipeg, by ASL Environmental Sciences Inc., Victoria, B.C. Canada: iv + 18 p.

Niemi, A., Johnson, J., Majewski, A., Melling, H. Reist, H. and Williams, W. 2012. State of the Ocean Report of the Beaufort Sea Large Ocean Management Area. Can. Manuscr. Rep. Fish. and Aquat. Sci. 2977: vi + 51p.

Noel, M. Loseto, L., Helbing, C., Veldhoen, N. and Ross, P. (In Review). Change in diet and contaminants are affecting the expression of essential genes in the Western Arctic beluga whales. Submitted to Environmental Science and Technology.

Quakenbush, L., Citta, J., George, J., Small, R. and Heide-Jørgensen, M. 2010. Fall and winter movements of bowhead whales (*Balaena mysticetus*) in the Chukchi Sea and within a potential petroleum development area. Arctic **63(3)**: 289-307.

Quakenbush, L., Citta, J., George, J., Heide-Jørgensen, M., Small, R., Brower, H., Harwood, L., Adams, B., Brower, L., Tagarook, G., Pokiak, C. and Pokiak, J. 2012. Seasonal movements of the Bering-Chukchi-Beaufort stock of bowhead whales: 2006–2011 satellite telemetry results. International Whaling Commission Scientific Technical Committee report, May 2012.

Tang, S., Larouche, P., Niemi, A. and Michel, C. 2013. Regional algorithms for remote-sensing estimates of total suspended matter in the Beaufort Sea. International Journal of Remote Sensing **34(19)**: 6562-6576.

Tremblay, J.-É., Bélanger, S., Barber, D., Asplin, M., Martin, J., Darnis, G., Fortier, L., Gratton, Y., Link, H., Archambault, P., Sallon, A., Michel, C., Williams, W.,

Phillipe, B. and Gosselin, M. 2011. Climate forcing multiplies biological productivity in the coastal Arctic. Geophysical Research Letters **38**: L18604.

Walkusz W. (in prep). Dead by mixing – potential mass mortality of marine zooplankton in the Mackenzie River plume influenced Canadian Beaufort Shelf.

Walkusz W., Majewski A., Niemi A., Loseto L., Lowdon K., Munro C., Gale M. and Beaudry C. 2010. Arctic Coastal Ecosystem Studies: Shingle Point – Shallow Bay, July 2010. Field Report. 27 p.

Walkusz W., Loseto L. and Majewski A., 2011. Arctic Coastal Ecosystem Studies: Shingle Point – Shallow Bay, July – August, 2011. Field Report. 15 p.

Walkusz, W., Williams, W., Harwood, L., Moore, S., Stewart, B. and Kwasniewski, S. 2012. Composition, biomass and energetic content of biota in the vicinity of feeding bowhead whales (*Balaena mysticetus*) in the Cape Bathurst upwelling region (south eastern Beaufort Sea). Deep-Sea Research I **69**: 25-35.